

**Water Year 2005
Overview of Surface Water
Monitoring Data for SC, SAR and Flow
in the Powder River Watershed**



This cover photo shows an aerial photograph of the confluence of the Powder River with the Yellowstone River near Terry, MT

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Introduction

When Coal Bed Natural Gas (CBNG) is developed it is necessary to cause the methane to desorb from the coal, and flow to production wells. This is typically achieved by pumping groundwater from the coal bed aquifer being developed, since this reduces the hydrostatic pressure within the coal seam (allowing the methane to desorb) and creates a pressure gradient within the aquifer that causes methane to flow towards the pumping wells. This coal seam water in the Powder River Basin is typically moderately saline, having a Specific Conductance (SC; which is proportional to salinity) on the order of 2,000 microSiemens per centimeter ($\mu\text{S}/\text{cm}$). High salinity irrigation water may result in decreased crop yields depending on the crop being grown (See Fig. 1). Since the MDEQ regulations define Electrical Conductivity (EC) as “the ability of water to conduct an electrical current at 25°C. The electrical conductivity of water represents the amount of total dissolved solids in the water and is expressed as microSiemens/centimeter ($\mu\text{S}/\text{cm}$) or micromhos/centimeter ($\mu\text{mhos}/\text{cm}$) or equivalent units and is corrected to 25°C” the SC values discussed in this report are directly comparable to the EC standards. CBNG water is a sodium-bicarbonate (Na-HCO_3) type water, while surface waters are typically relatively balanced. This dominance of sodium cations cause CBNG water to have a high Sodium Adsorption Ratio (SAR; which is a complex ratio of Na to $\text{Ca}+\text{Mg}$); typically between 20 and 60. High SAR values may cause impacts to soil structure, and impair the ability for clay rich soils to infiltrate water (see Fig. 2). There is also little sulfate in the water in productive coal seams (VanVoast, 2003). Much of the produced water is managed through treated or untreated discharge to surface waters under National Pollutant Discharge Elimination System (NPDES) permits.

In Montana, NPDES permitting is conducted by the Montana Department of Environmental Quality (MDEQ) under the Montana Pollutant Discharge Elimination System (MPDES) permit program. There are currently no permits for CBNG discharge to the Powder River in Montana.

In Wyoming, NPDES discharge permitting is conducted by the Wyoming Department of Environmental Quality (WDEQ) under the Wyoming Pollutant Discharge Elimination System (WYPDES). Surface discharge, either with or without treatment, and to on and off channel impoundments are the major methods of water management in the Wyoming portion of the Powder River watershed (McKinley, pers com. 2006).

Large scale CBNG development began in Wyoming and Montana, in approximately 1999; within the first CBNG discharge in Montana occurring in September, 1999. In response to the potential for CBNG development in the Powder River Basin, the MDEQ has developed surface water quality standards for EC and SAR in the Powder River watershed. These standards provide criteria against which to compare the monitoring data. These standards are summarized in Table 1 below. The MDEQ standards have been reviewed and approved by the United States Environmental Protection Agency (EPA), and therefore have Clean Water Act standing. Also, note that irrigation season standards are different from the non-irrigation season. MDEQ standards are applicable at the Wyoming-Montana state line; however they are not applicable in Wyoming. It

should be noted that these values are used solely as a point of comparison; the comparisons in this report do not constitute regulatory determinations.

The Montana Board of Environmental Review (BER) has modified the standards which apply to CBNG in Montana; however this report only considers those standards which were in place in water year 2005. The most substantial change adopted by the BER was to designate EC and SAR “harmful” parameters, which causes non-degradation rules to apply.

Table 1. MDEQ Standards for EC and SAR in the Powder River Watershed

	Irrigation Season (March-October)				Non-Irrigation Season (November-February)			
Stream	Mean Monthly EC (uS/cm)	NTE EC (uS/cm)	Mean Monthly SAR	NTE SAR	Mean Monthly EC (uS/cm)	NTE EC (uS/cm)	Mean Monthly SAR	NTE SAR
Powder River	2000	2500	5	7.5	2500	2500	6.5	9.75
Little Powder River	2000	2500	5	7.5	2500	2500	6.5	9.75
Tributaries	500	500	3	4.5	500	500	5	7.5

NTE = Not to Exceed

EC = Electrical Conductance

SAR = Sodium

uS/cm = microSiemens per centimeter

Adsorption Ratio

The Interagency working group for CBNG has identified regional surface water monitoring stations for the Powder River watershed. These stations, with their status for water year 2005 (10/1/05-9/30/06) are listed on Table 2 below. The locations of the active stations are shown on Map 1. Data collected at these stations included continuous flow, continuous specific conductance (SC), and analytical sampling. Analytical sampling includes the measurement of flow, field parameters (SC, pH, temperature, etc) and includes the collection of water-quality samples. Although these samples were analyzed by the USGS for many parameters, this report will focus on SC, SAR, and flow. SC and SAR are considered to be the parameters most likely to be affected by CBNG development (MDEQ, 2003b), and SC and SAR in the natural system fluctuate significantly with flow. The monitoring at these stations was funded by the USGS, WDEQ, WSEO, MDEQ, and MDNRC. An expanded set of analytical data are available from the USGS at <http://waterdata.usgs.gov/nwis>.

Table 2: Regional USGS Stations in the Powder River Watershed

Station #	Station Name	Status
06313500	Powder River at Sussex, WY	Flow and QW
06313605	Powder River below Burger Draw, near Buffalo, WY	QW
06317000	Powder River at Arvada, WY	Flow and QW
06324500	Powder River near Moorhead, MT	Flow and QW
06324710	Powder River at Broadus, MT	Inactive
06325650	Powder River at Powderville	Inactive
06326500	Powder River near Locate, MT	Flow and QW
06316400	Crazy Woman at Upper Station, near Arvada, WY	Flow and QW
06324000	Clear Creek near Arvada, WY	Flow and QW
06324970	Little Powder River above Dry Creek near Weston, WY	Flow and QW
06325500	Little Powder River near Broadus, MT	QW
06326300	Mizpah at Mizpah	Inactive

QW = Water Quality

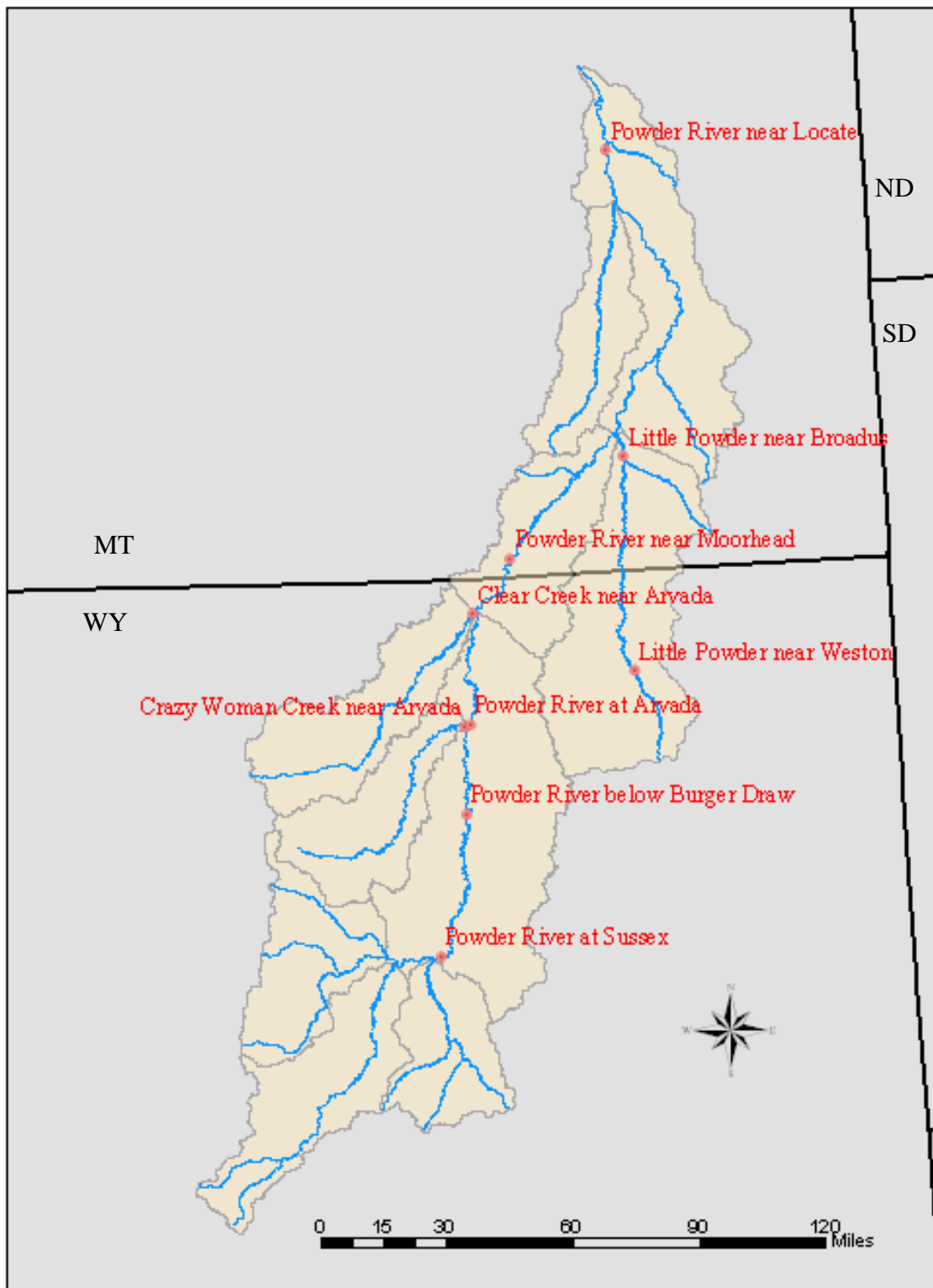
Data Review

For all sites, please see the figures section for graphical display of the data. Tabulated summary statistics for the sites are provided on Tables 3 and 4 below. Note that much of this data is preliminary so there may be slight differences between this data and the final data eventually released by the USGS.

For each station a summary of the mean daily flow, SC, and SAR data collected during water year 2005 is presented. Analytical Flow, SC and SAR data are also presented. Analytical results are compared to the MDEQ “not to exceed” (NTE) surface water standards for EC and SAR where they are applicable. For comparison to the mean monthly EC and SAR standards the mean monthly values are calculated as the simple average of all the mean daily and analytical measurements recorded during each calendar month. For several stations only monthly analytical samples are collected, so the mean monthly values are the same as the analytical values. Note that within the figures section the daily mean and analytical data are combined when discussing the range of values recorded. SC vs. Flow, SAR vs. Flow, and SC vs. SAR with historical data are presented in graphical form to allow evaluation of 2005 data in context.

Since SC and SAR are dependent on flow, it is important to recognize up front that water year 2005 was substantially wetter than 2004, with flows near long-term averages. Therefore, it is believed that data from 2005 may provide a better representation of “normal” conditions. If comparison is made between water quality data from different years, it is important to also take flow into account.

Map 1



Map 1 shows the Powder River Watershed as it extends from Wyoming into Montana. The locations of the 11 surface water monitoring sites (6 in Wyoming, 3 in Montana), which are the subject of this report, are also shown.

Main Stem Sites

Powder River at Sussex

Flow was measured continuously at this site. Water-quality samples were also collected. Mean daily flow values ranged from 5.6 to 2400 cfs, with the mean being 121 cfs (see Fig. 3).

Analytical SC values at this site ranged from 1020 to 6140 $\mu\text{S}/\text{cm}$, with the mean being 2926 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 3.4 to 21 with the mean being 7.9 (see Figs. 4-7).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 5-7).

Powder River below Burger Draw

Flow was measured during sampling events at this site. Water-quality samples were also collected. Measured flow values ranged from 4.6 to 293 cfs, with the mean being 103 cfs (see Fig. 8).

Analytical SC values at this site ranged from 1780 to 4480 $\mu\text{S}/\text{cm}$, with the mean being 2848 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 5.0 to 14 with the mean being 7.8 (see Figs. 9-12).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 10-12).

Powder River at Arvada

Flow was measured continuously at this site. Water-quality samples were also collected. Mean daily flow values ranged from 0 to 3080 cfs, with the mean being 176 cfs (see Fig. 13).

Analytical SC values at this site ranged from 916 to 3640 $\mu\text{S}/\text{cm}$, with the mean being 2393 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 2.8 to 8.5 with the mean being 5.9 (see Figs. 14-17).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 15-17).

**Table 3: 2005 Summary Statistics for Mainstem Sites
in the Powder River Watershed**

		Mean Daily		Analytical			Mean Monthly	
		Flow (cfs)	SC (uS/cm)	Flow (cfs)	SC (uS/cm)	SAR	SC (uS/cm)	SAR
Powder River at Sussex, WY*	n	365	---	24	24	24	12	12
	min	5.6	---	7.7	1020	3.4	1145	3.4
	max	2400	---	454	6140	21	5925	20
	mean	121	---	116	2926	7.9	2927	7.9
	median	109	---	112	2505	5.9	2540	6.4
Powder River below Burger Draw, near Buffalo, WY*	n	---	---	12	12	12	12	12
	min	---	---	4.6	1780	5.0	1780	5.0
	max	---	---	293	4480	14	4480	14
	mean	---	---	103	2848	7.8	2849	7.8
	median	---	---	97	2600	6.4	2580	6.1
Powder River at Arvada, WY*	n	365	---	23	23	23	12	12
	min	0	---	0	916	2.8	1350	3.5
	max	3080	---	850	3640	8.5	3640	8.1
	mean	176	---	167	2393	5.9	2445	5.9
	median	115	---	123	2470	5.9	2430	6.5
Powder River near Moorhead, MT	n	365	248	24	24	24	12	12.0
	min	27	450	46	500	1.5	949	1.6
	max	2900	2680	2050	2540	6.5	2143	5.8
	mean	339	1605	314	1696	3.8	1711	3.8
	median	173	1660	203	1840	4.2	1667	3.9
Powder River near Locate, MT	n	365	---	12	12	12	12	12
	min	25	---	50	838	3.7	838	3.7
	max	3390	---	3280	2870	6.4	2870	6.4
	mean	390	---	415	2025	5.1	2029	5.1
	median	159	---	145	2070	5	2090	5.3

SC = Specific Conductance

SAR = Sodium Adsorption Ratio

cfs = cubic feet per second

Indicates exceedance of applicable Irrigation Season Standards.

uS/cm = microSiemens per centimeter

n = number of data points

---- = no data

* = MDEQ Standards do not apply.

Powder River near Moorhead

Flow and SC were measured continuously at this site; however SC was not collected in the winter (11/1/04 through 3/8/05). Water-quality samples were also collected. Mean daily flow values ranged from 27 to 2900 cfs, with the mean being 339 cfs (see Fig. 18).

Mean daily SC data collected at this station ranged from 450 to 2680 $\mu\text{S/cm}$, with a mean value of 1605 $\mu\text{S/cm}$ (see Fig. 24). Analytical SC values at this site ranged from 500 to 2540 $\mu\text{S/cm}$, with the mean being 1696 $\mu\text{S/cm}$. Analytical SAR values at this site ranged from 1.5 to 6.5 with the mean being 3.8 (see Figs. 19-22).

Recorded SC values were above the EC instantaneous maximum standard on three occasions (12/1/04, 1/4/05 and 7/25/05). SAR values did not exceed the instantaneous maximum standard. Mean monthly SC values were in excess of the mean monthly EC standard during March and April. Mean monthly SAR values were in excess of the mean monthly SAR standard during March and April (see Fig. 19).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 20-22).

Powder River near Locate

Flow was measured continuously at this site. Water-quality samples were also collected. Mean daily flow values ranged from 25 to 3390 cfs, with the mean being 390 cfs (see Fig. 23).

Analytical SC values at this site ranged from 838 to 2870 $\mu\text{S}/\text{cm}$, with the mean being 2025 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 3.7 to 6.4 with the mean being 5.1 (see Figs. 24-27).

Recorded SC values were above the EC instantaneous maximum standard for 2 of the 12 samples collected. SAR values did not exceed the instantaneous maximum standard. Mean monthly SC values were in excess of the mean monthly EC standard during December, January, March, April May, August, and September; however there was only one SC sample collected in each month. Mean monthly SAR values were in excess of the mean monthly SAR standard during March, April, May, and August; however there was only one SAR sample collected in each month (see Fig. 24).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 25-27).

Tributary Sites

Crazy Woman Creek near Arvada

Flow was measured continuously at this site. Water-quality samples were also collected. Mean daily flow values ranged from 0.36 to 559 cfs, with the mean being 40 cfs (see Fig. 28).

Analytical SC values at this site ranged from 442 to 2840 $\mu\text{S}/\text{cm}$, with the mean being 1527 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 0.9 to 3.1 with the mean being 1.8 (see Figs. 29-32).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 30-32).

Clear Creek near Arvada

Flow was measured continuously at this site. Water-quality samples were also collected. Mean daily flow values ranged from 11 to 1910 cfs, with the mean being 165 cfs (see Fig. 33).

Analytical SC values at this site ranged from 279 to 1280 $\mu\text{S}/\text{cm}$, with the mean being 959 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 0.5 to 1.3 with the mean being 1.1 (see Figs. 34-37).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 35-37).

**Table 4: 2005 Summary Statistics for Tributary Sites
in the Powder River Watershed**

		Mean Daily		Analytical			Mean Monthly	
		Flow (cfs)	SC ($\mu\text{S}/\text{cm}$)	Flow (cfs)	SC ($\mu\text{S}/\text{cm}$)	SAR	SC ($\mu\text{S}/\text{cm}$)	SAR
Crazy Woman, near Arvada, WY*	n	365	---	24	23	24	12	12
	min	0.36	---	0.40	442	0.9	548	1.0
	max	559	---	257	2840	3.1	2765	3.0
	mean	40	---	36	1527	1.8	1535	1.8
	median	12	---	13	1520	1.7	1510	1.8
Clear Creek near Arvada, WY*	n	365	---	25	25	24	12	12.0
	min	11	---	27	279	0.5	331	0.5
	max	1910	---	924	1280	1.3	1195	1.3
	mean	165	---	155	959	1.1	947	1.1
	median	78	---	79	1000	1.2	974	1.1
Little Powder River above Dry Creek near Weston, WY*	n	365	---	12	12	12	12	12
	min	0	---	0	1540	5.1	1540	5.1
	max	415	---	10	4240	7.6	4240	7.6
	mean	8.2	---	2.6	2784	6.4	2783	6.4
	median	1.4	---	1.8	2845	6.6	2820	6.3
Little Powder River near Broadus, MT	n	---	---	12	12	12	12	12.0
	min	---	---	1.4	1650	6.5	1650	6.5
	max	---	---	20	3360	15	3360	15
	mean	---	---	7.6	2552	8.9	2550	9.0
	median	---	---	6.4	2580	7.9	2490	8.1

SC = Specific Conductance

SAR = Sodium Adsorption Ratio

cfs = cubic feet per second

Indicates exceedance of applicable Irrigation Season Standards.

$\mu\text{S}/\text{cm}$ = microSiemens per centimeter

n = number of data points

--- = no data

* = MDEQ Standards do not apply.

Little Powder near Weston

Flow was measured continuously at this site. Water-quality samples were also collected. Mean daily flow values ranged from 0 to 415 cfs, with the mean being 8.2 cfs (see Fig. 38).

Analytical SC values at this site ranged from 1540 to 4240 $\mu\text{S}/\text{cm}$, with the mean being 2784 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 5.1 to 7.6 with the mean being 6.4 (see Figs. 39-42).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 40-42).

Little Powder near Broadus

Flow was measured during sampling events at this site. Water-quality samples were also collected. Measured flow values ranged from 1.4 to 20 cfs, with the mean being 7.6 cfs (see Fig. 43).

Analytical SC values at this site ranged from 1650 to 3360 $\mu\text{S}/\text{cm}$, with the mean being 2552 $\mu\text{S}/\text{cm}$. Analytical SAR values at this site ranged from 6.6 to 15 with the mean being 8.9 (see Figs. 44-47).

Recorded SC values were above the EC instantaneous maximum standard for six of the twelve samples collected. SAR values were in excess of the instantaneous maximum standard for seven of the twelve samples collected. Mean monthly SC values were in excess of the mean monthly EC standard for eight months; however there was only one SC sample collected in each month. Mean monthly SAR values were in excess of the mean monthly SAR standard during for eleven of the twelve samples collected; however there was only one SAR sample collected in each month (see Fig. 44).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2005 data along with historical data (see Figs. 45-47).

Conclusions

During Water Year 2005 (October 2004-September 2005) flows within the Powder River watershed were comparable to historical averages. EC and SAR can be correlated with flow so an evaluation of EC and SAR must also take flow into account.

A comparison to the MDEQ surface water standards for EC and SAR showed that these standards are exceeded part of the time for every parameter at every station to which they apply. The uniform exceedance of these standards, even where little or no CBNG development has occurred, indicates that natural and/or non-CBNG conditions are responsible for these exceedances.

A statistical trend analysis was not conducted for this data; however an interpretive report is scheduled to be completed in 2007 which will include data through Water Year 2006.

References

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Reviewers

Mike Philbin	BLM, Billings, MT
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Figures

Figure 1: Comparison of Crop Yield to SC (Salinity) and Recorded 2005 SC Values in the Powder River Watershed

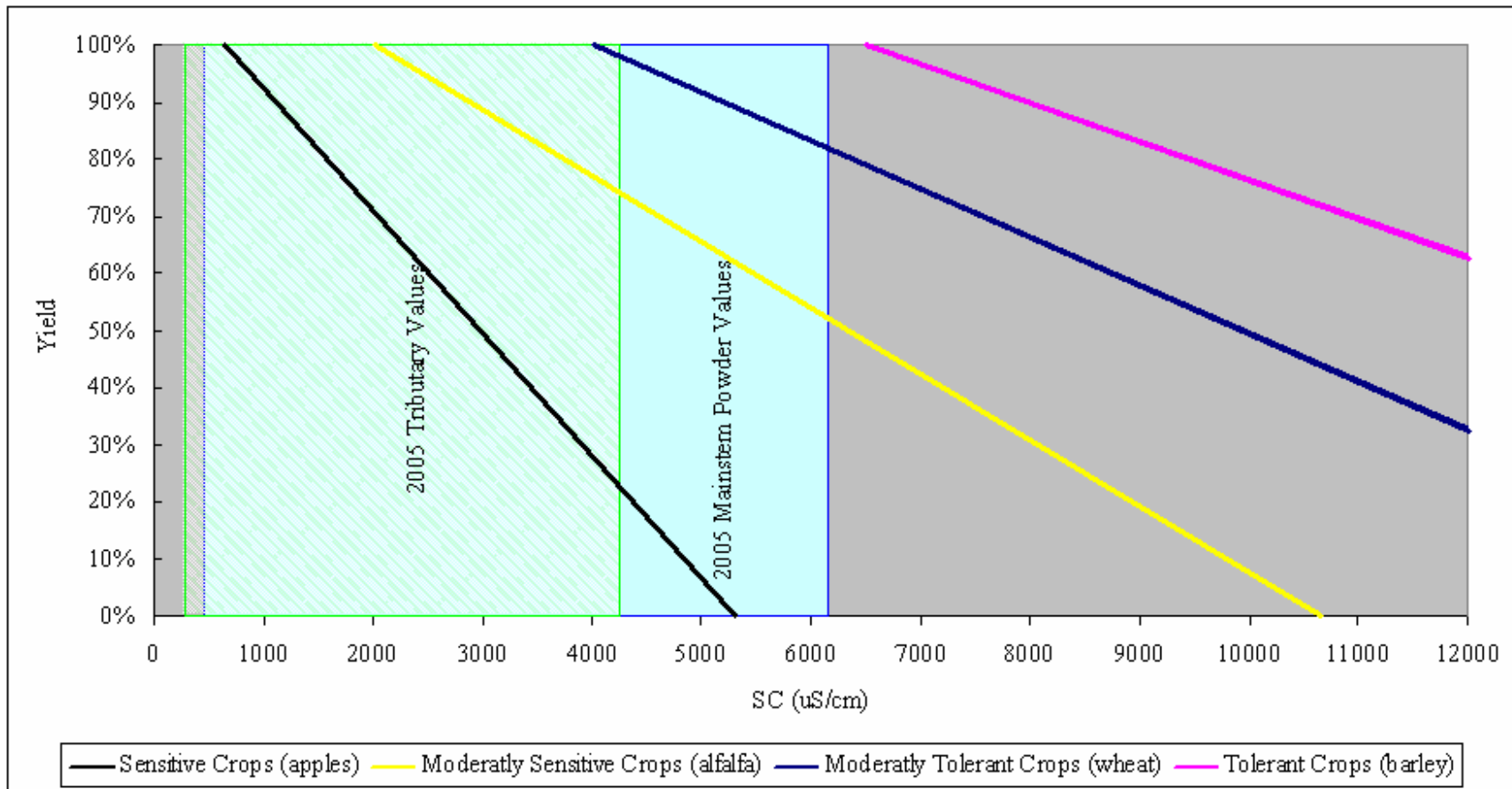


Figure 1 shows the range of SC values recorded during water year 2005 compared to yield vs. salinity curves for representative crops (Ayers and Westcott, 1999). Note that yield comparisons are made to that which would be attained using low salinity irrigation water, and assumes that all other factors are equal. Mainstem values ranged from 450 to 6140 uS/cm. Tributary values ranged from 279 to 4240 uS/cm.

Figure 2: Comparison of Infiltration Criteria and Recorded 2005 SC and SAR Values in the Powder River Watershed

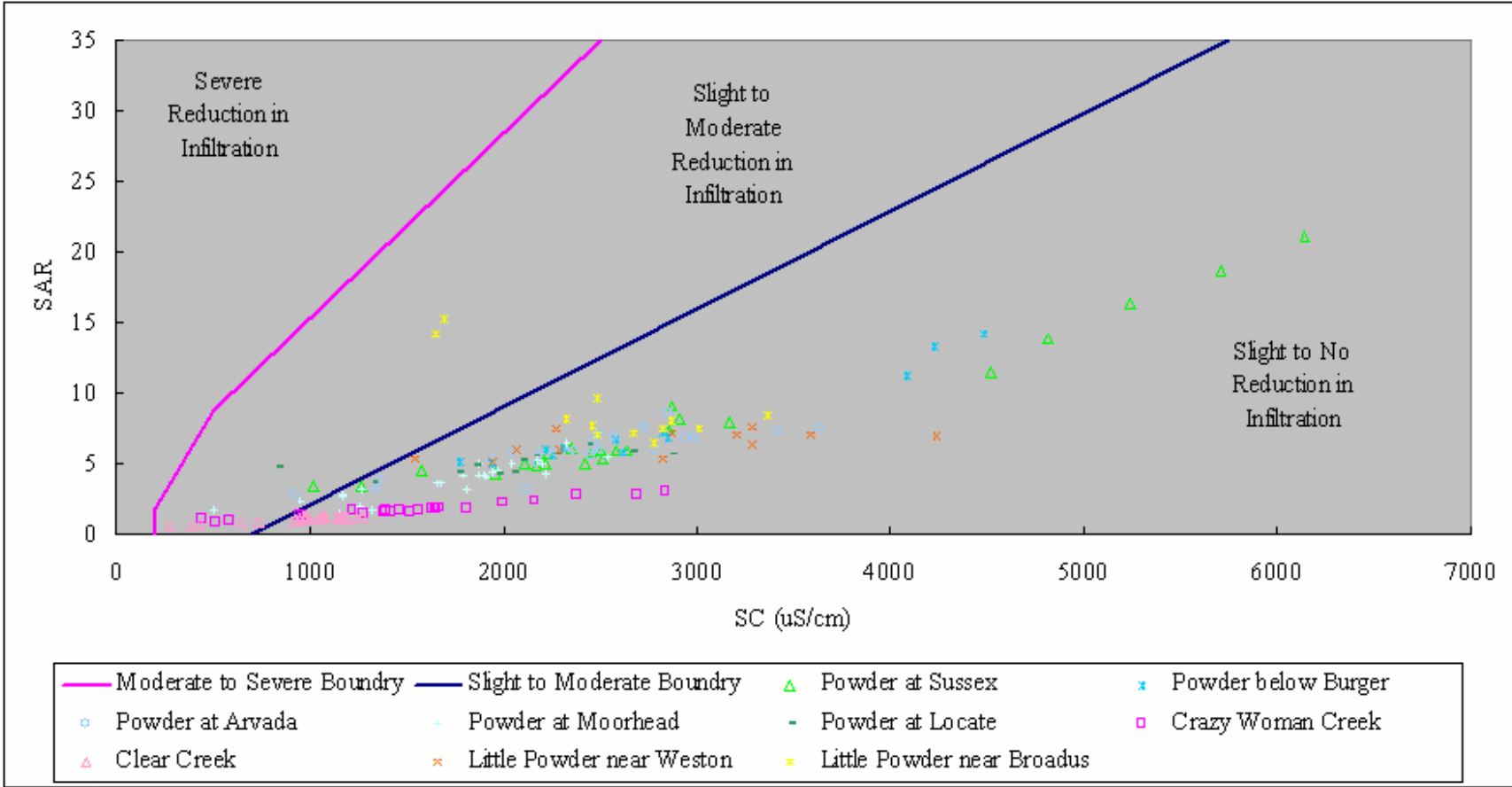


Figure 2 shows water quality data from water year 2005 in the Powder River Watershed compared to the infiltration criteria developed by Hanson et al. (1999). Most values fall within the Slight to No reduction in infiltration field; however particular samples from the Powder River at Sussex, Powder River at Moorhead, Powder River at Locate, Clear Creek, Crazy Woman Creek, and the Little Powder near Broadus fall within the Slight to Moderate reduction field.

Figure 3: Powder River at Sussex, WY

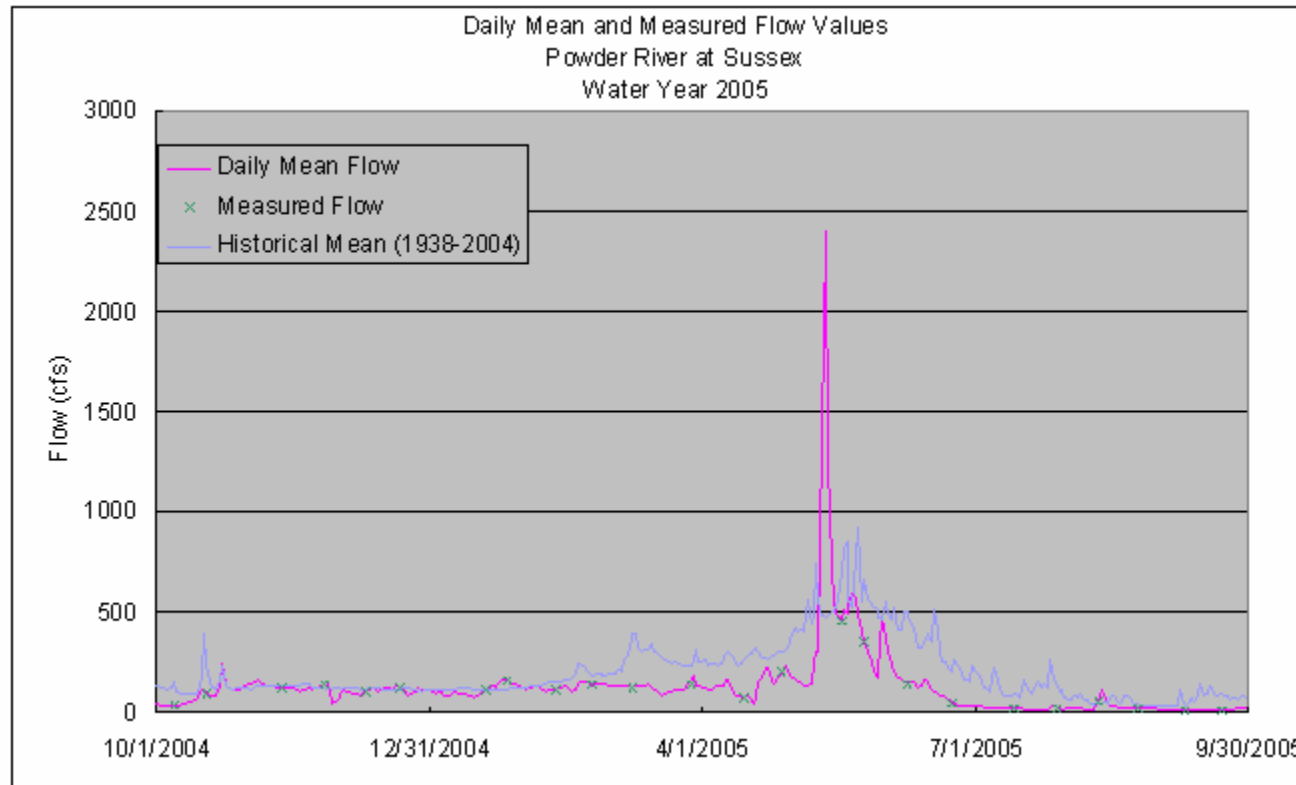


Figure 3 shows mean daily and field measurements of flow in a time series plot for water year 2005 for the Powder River at Sussex. Mean daily flow values ranged from 5.6 to 2400 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 4: Powder River at Sussex, WY

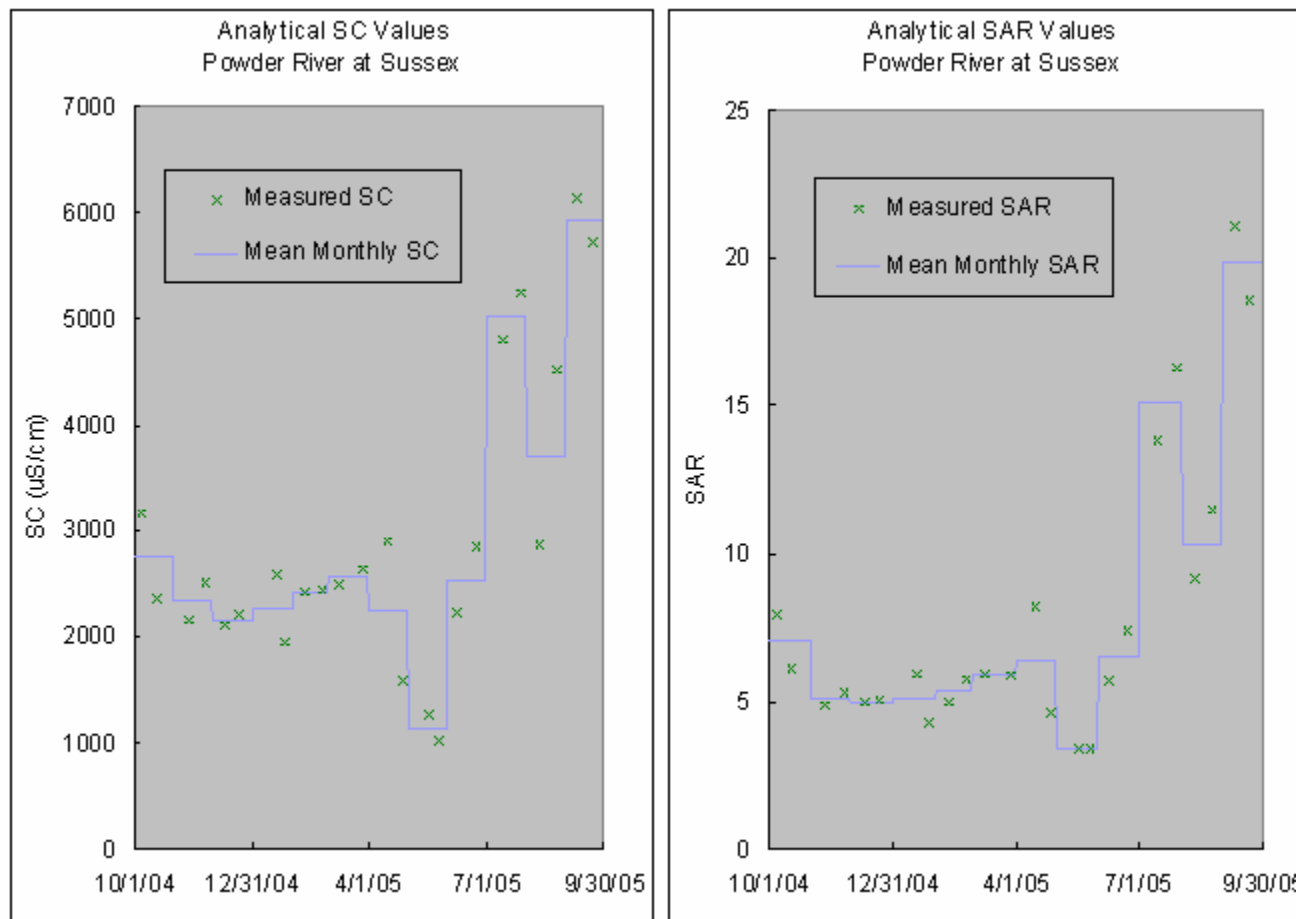


Figure 4 shows analytical SC values (A) and analytical SAR values (B) in time series plots for water year 2005 for the Powder River at Sussex. Mean Monthly SC and SAR values are also shown. SC values ranged from 1020 uS/cm to 6140 uS/cm. SAR values ranged from 3.4 to 21.

Figure 5: Powder River at Sussex, WY

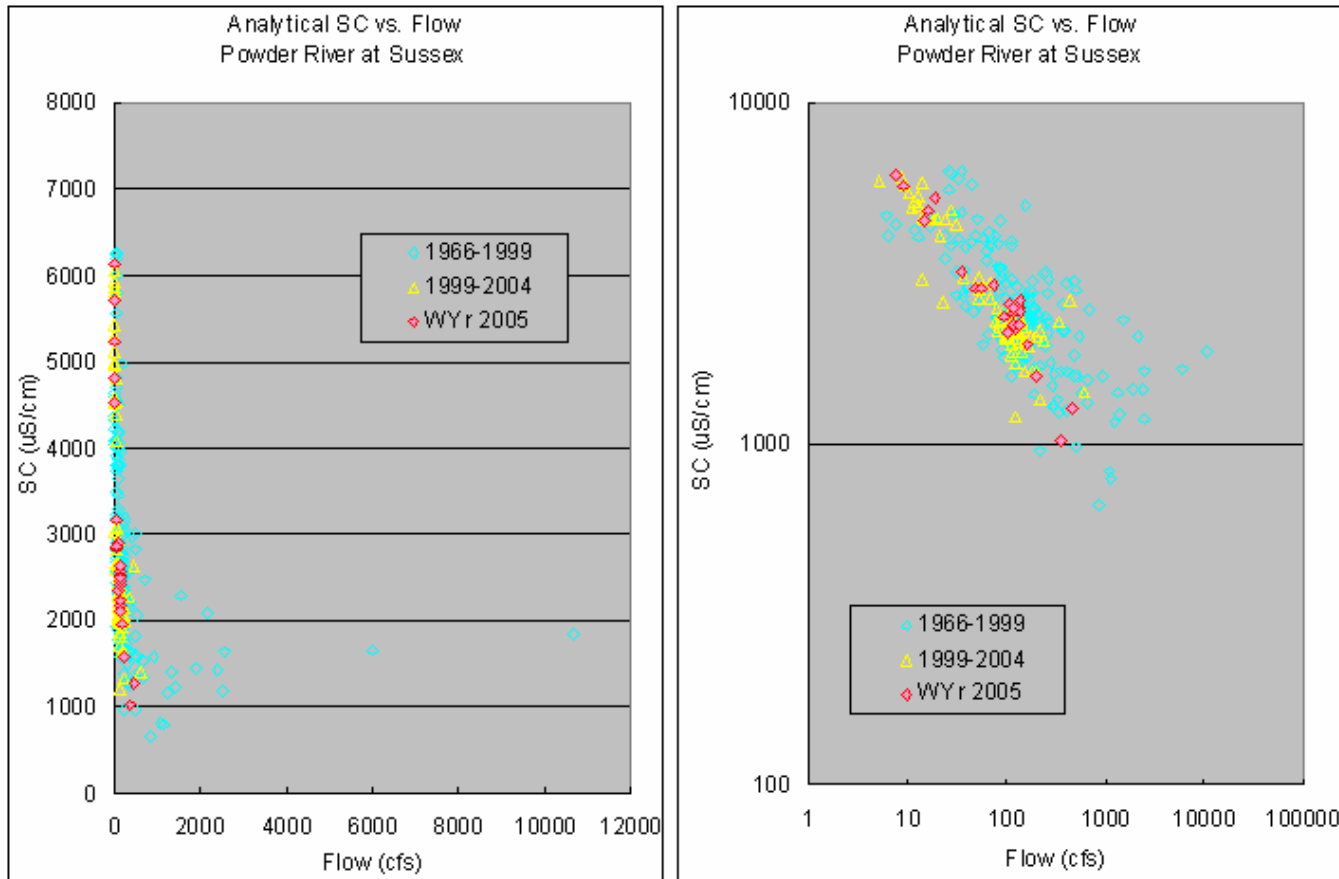


Figure 5 shows analytical SC vs. Flow data for water year 2005 for the Powder River at Sussex. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 6: Powder River at Sussex, WY

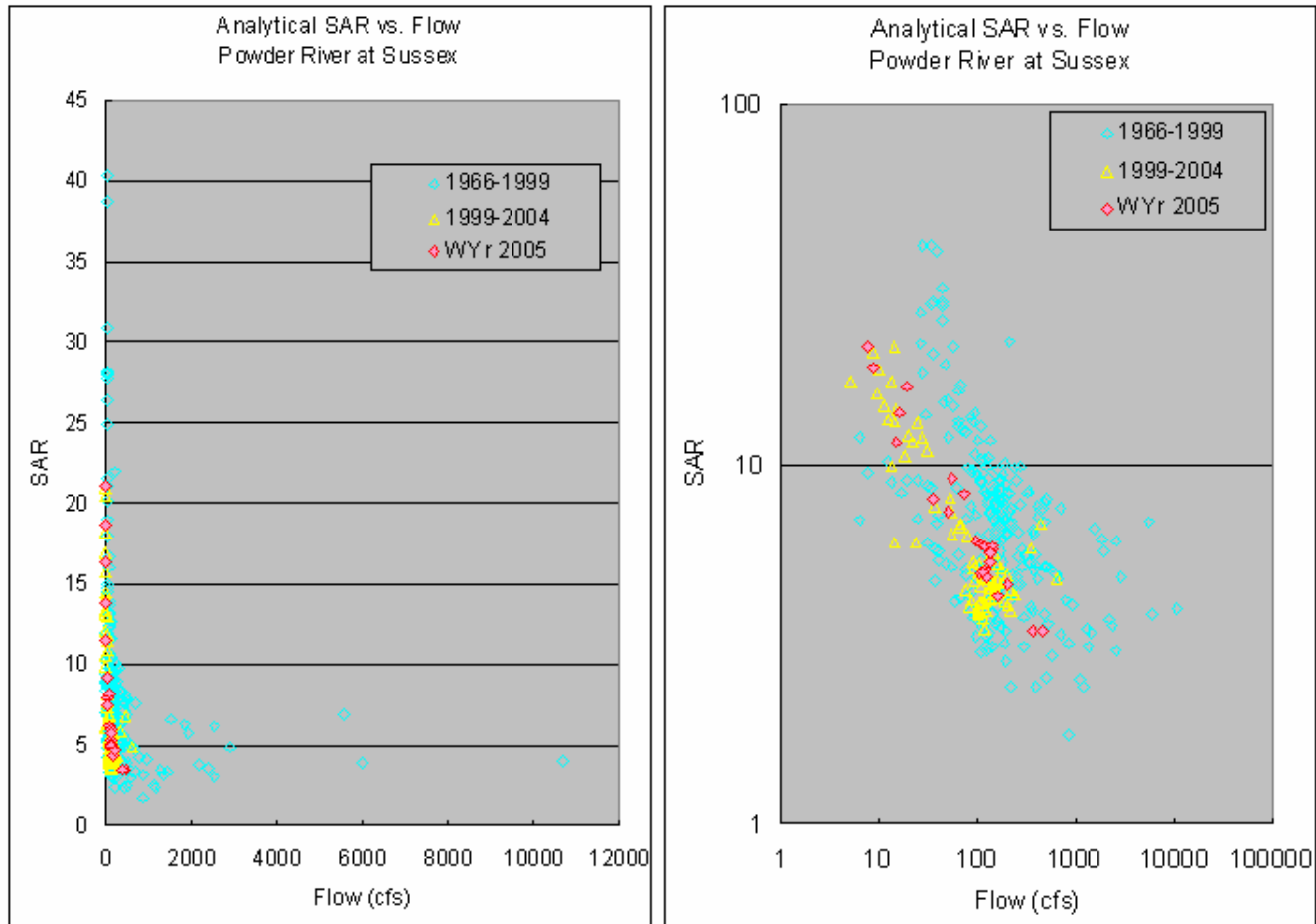


Figure 6 shows analytical SAR vs. Flow data for water year 2005 for the Powder River at Sussex. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 7: Powder River at Sussex, WY

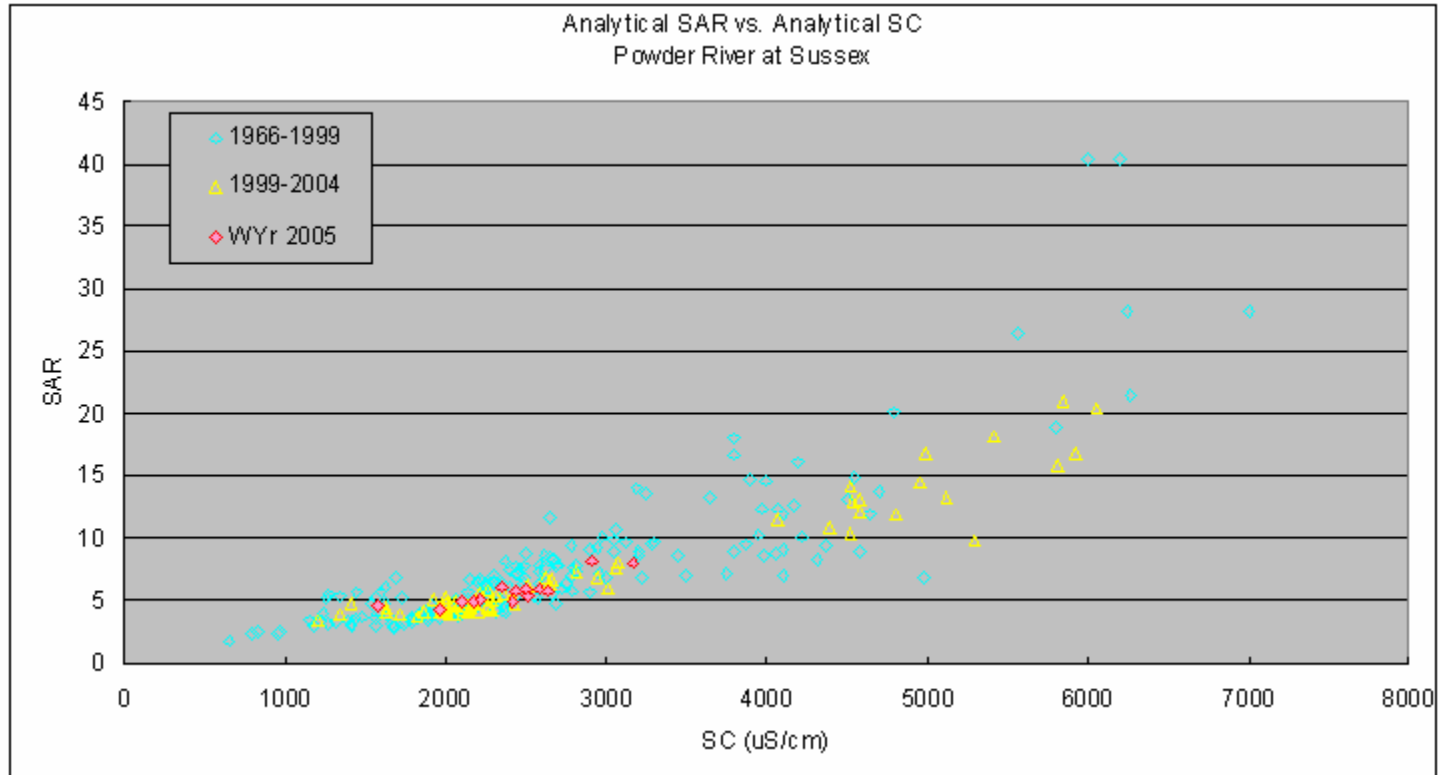


Figure 7 shows analytical SAR vs. analytical SC data for water year 2005 for the Powder River at Sussex. Historical SAR vs. SC data are also shown to place the data in context.

Figure 8: Powder River below Burger Draw, near Buffalo, WY

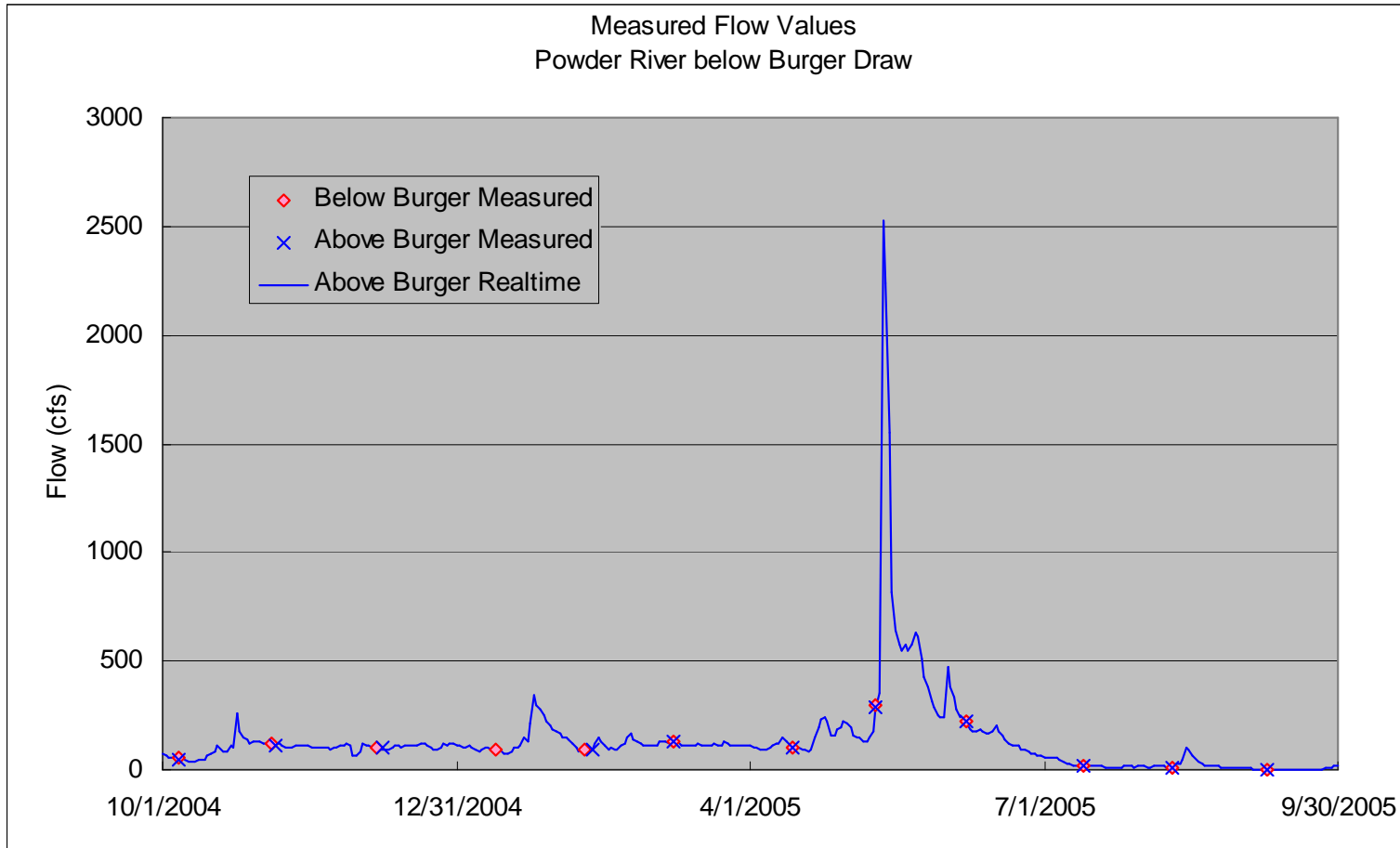


Figure 8 shows field measurements of flow in a time series plot for water year 2005 for the Powder River below Burger Draw. Recorded flow values ranged from 4.6 to 293 cfs. Values recorded above Burger Draw are also shown for comparison. The flow between the sites appears to be comparable.

Figure 9: Powder River below Burger Draw, near Buffalo, WY

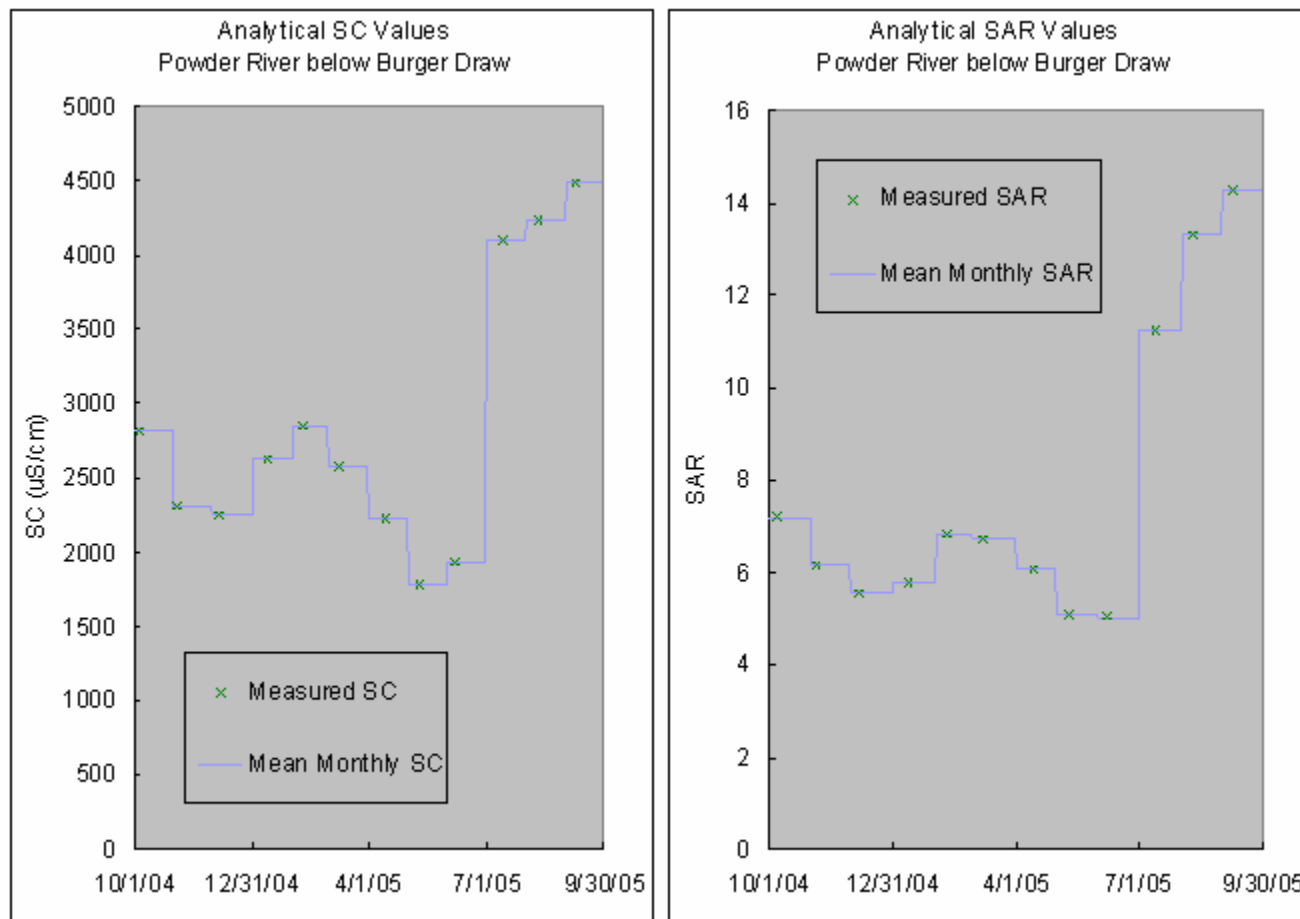


Figure 9 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2005 for the Powder River below Burger Draw. Mean Monthly SC and SAR values are also shown. SC values ranged from 1780 to 4480 uS/cm. SAR values ranged from 5.0 to 14.

Figure 10: Powder River below Burger Draw, near Buffalo, WY

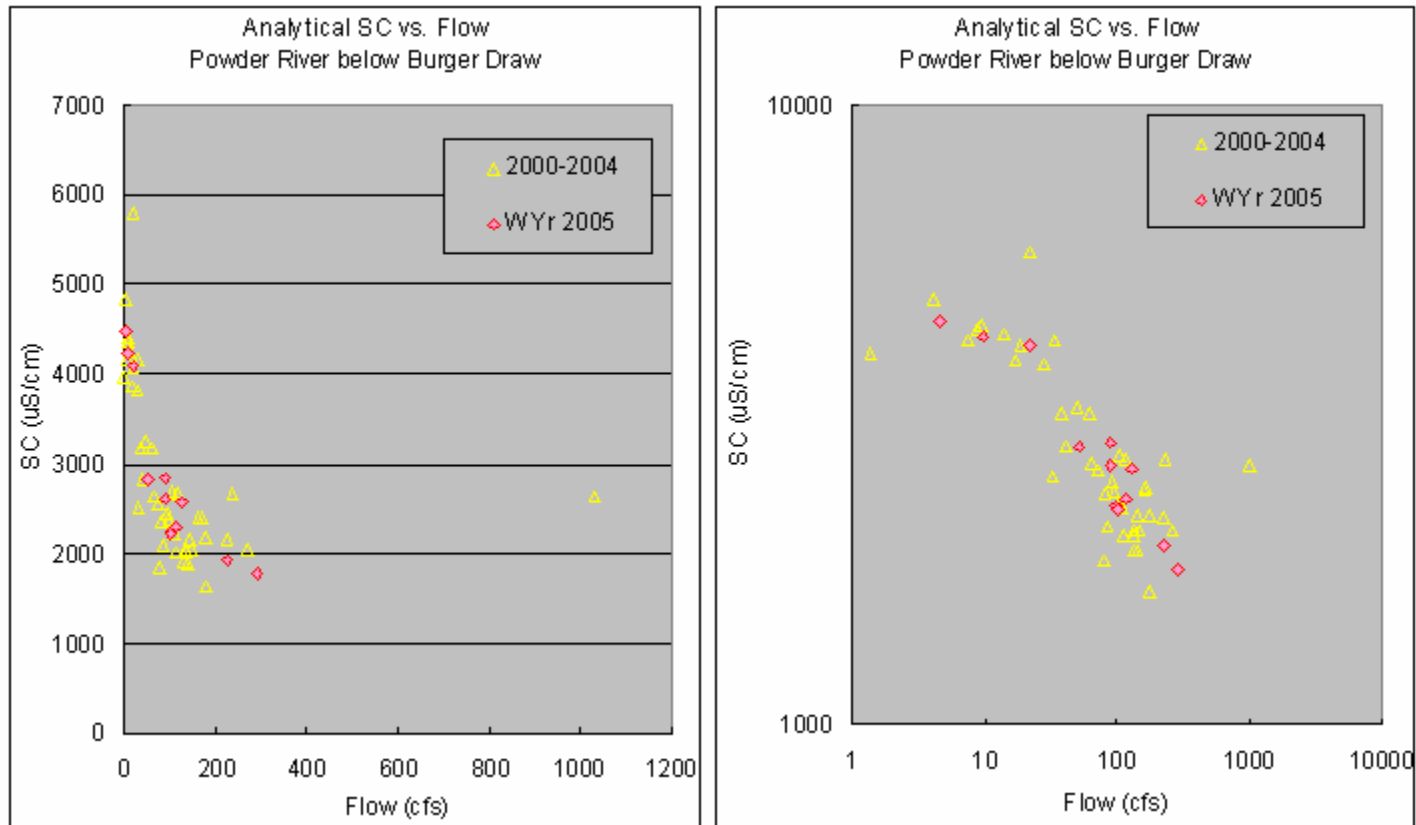


Figure 10 shows analytical SC vs. Flow data for water year 2005 for the Powder River below Burger Draw. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 11: Powder River below Burger Draw, near Buffalo, WY

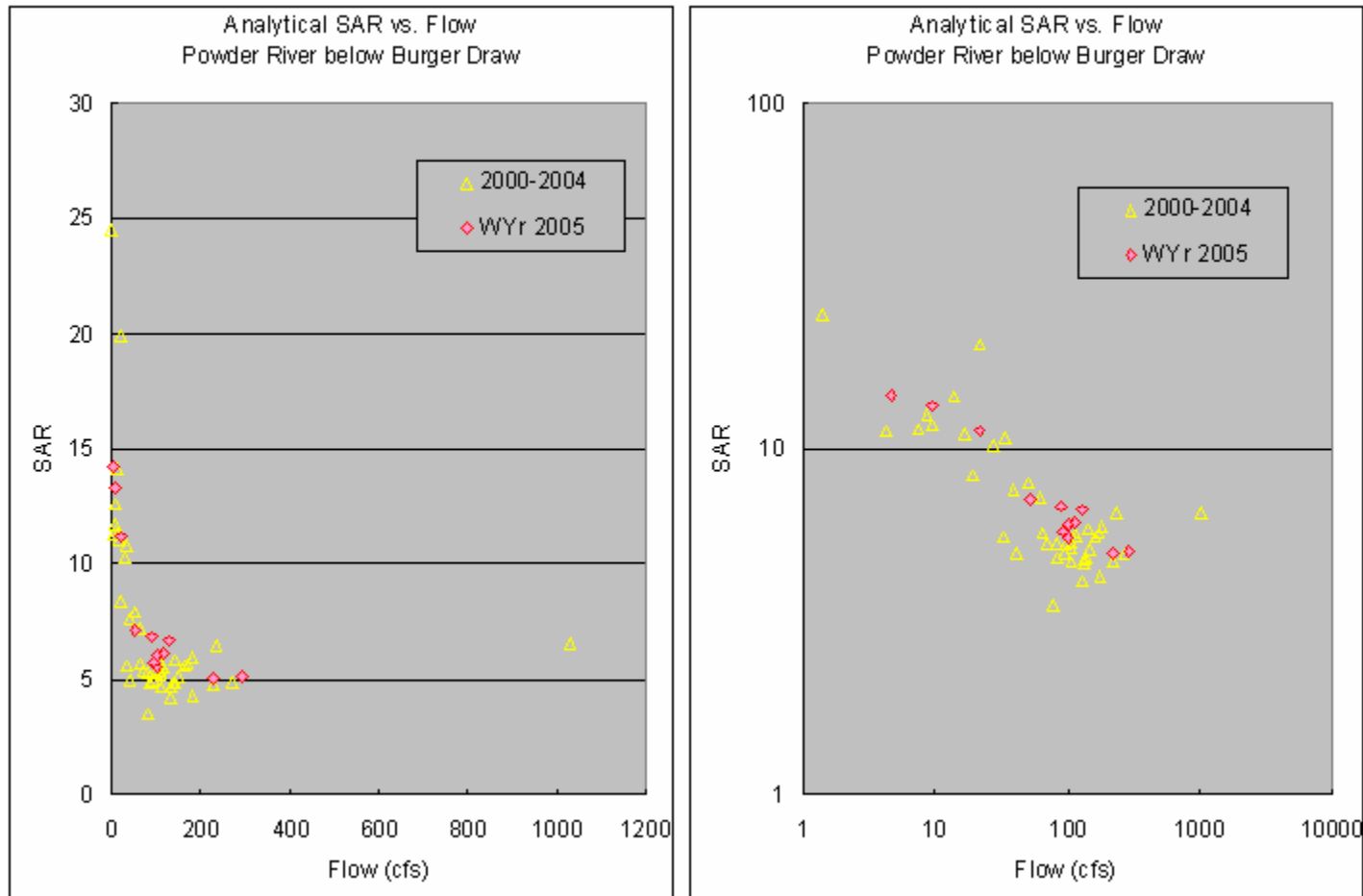


Figure 11 shows analytical SAR vs. Flow data for water year 2005 for the Powder River below Burger Draw. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 12: Powder River below Burger Draw, near Buffalo, WY

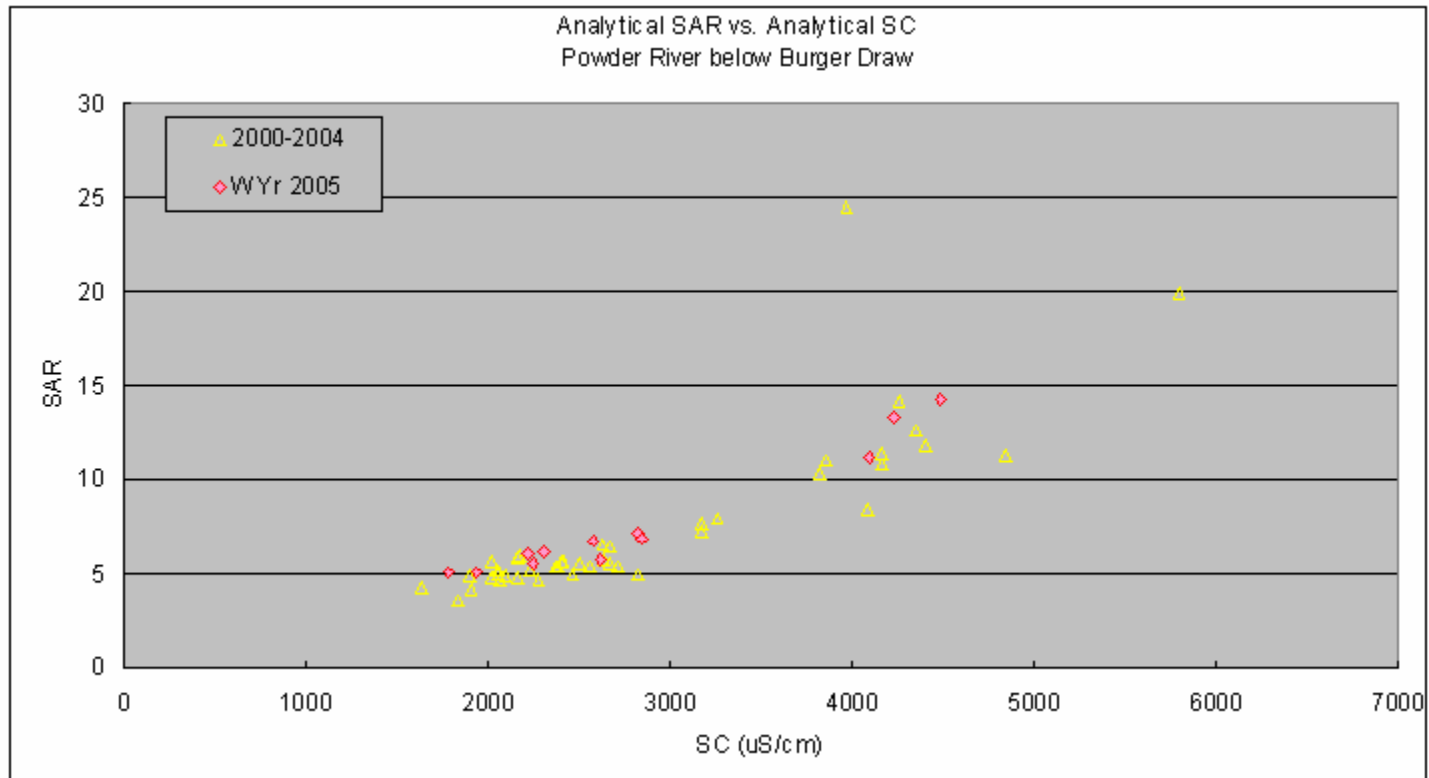


Figure 12 shows analytical SAR vs. analytical SC data for water year 2005 for the Powder River below Burger Draw. Historical SAR vs. SC data are also shown to place the data in context.

Figure 13: Powder River at Arvada, WY

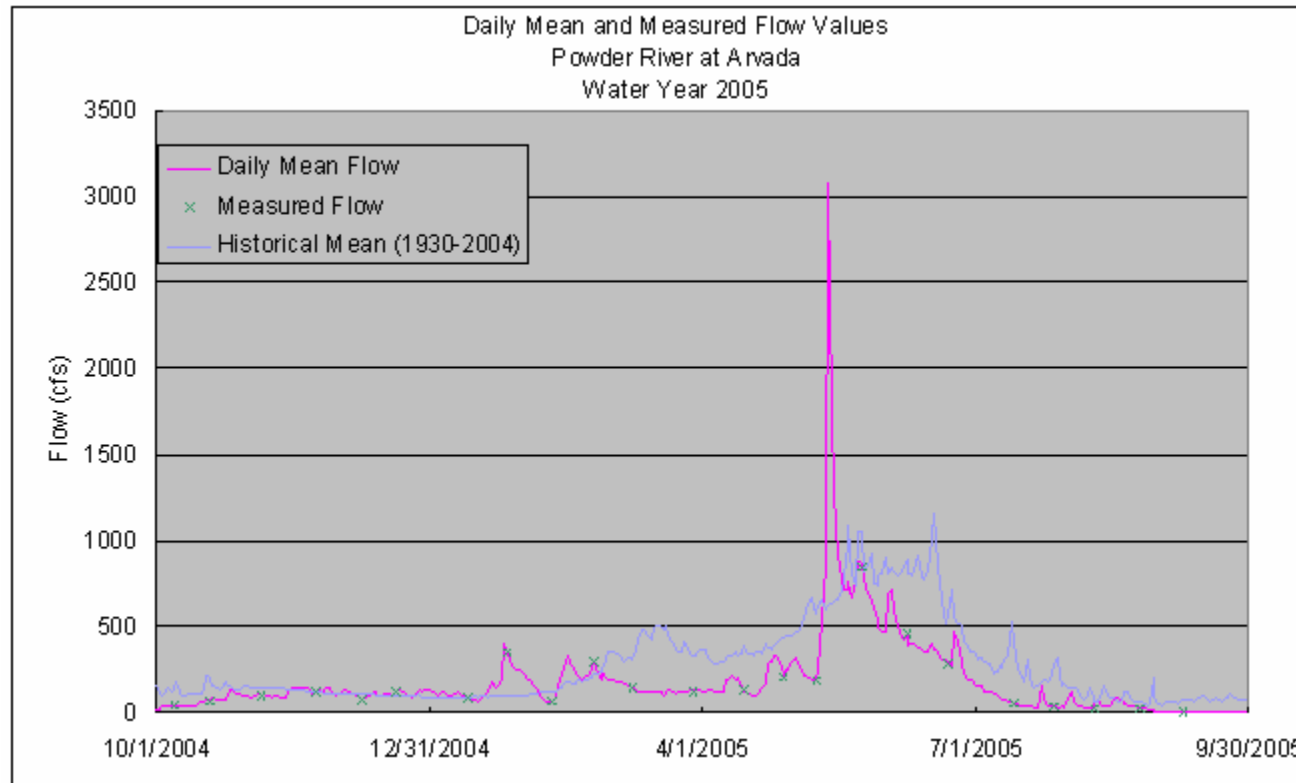


Figure 13 shows mean daily and field measurements of flow in a time series plot for water year 2005 for the Powder River at Arvada. Mean daily flow values ranged from 0 to 3080 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 14: Powder River at Arvada, WY

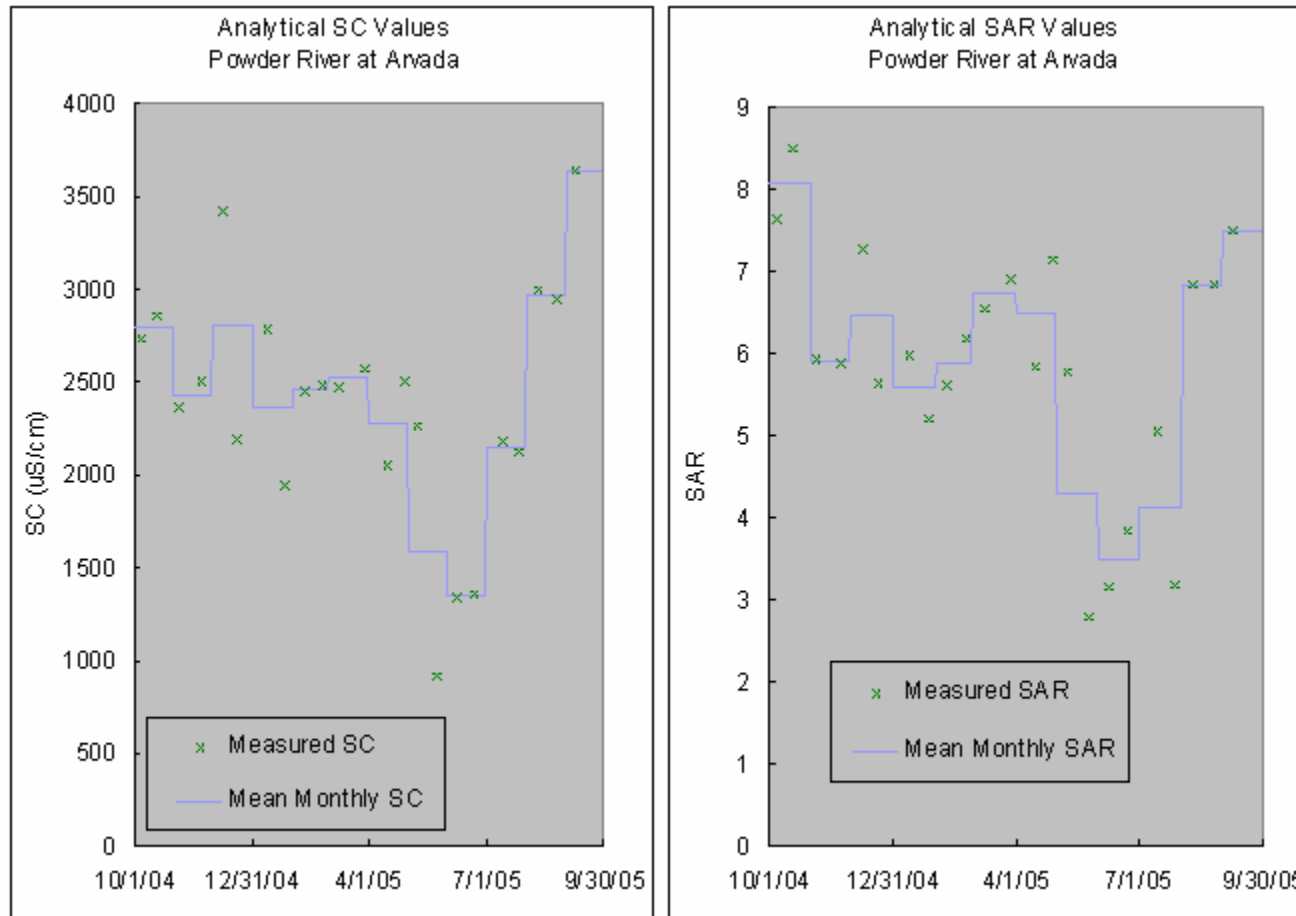


Figure 14 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2005 for the Powder River at Arvada. Mean Monthly SC and SAR values are also shown. SC values ranged from 916 to 3640 uS/cm. SAR values ranged from 2.8 to 8.5.

Figure 15: Powder River at Arvada, WY

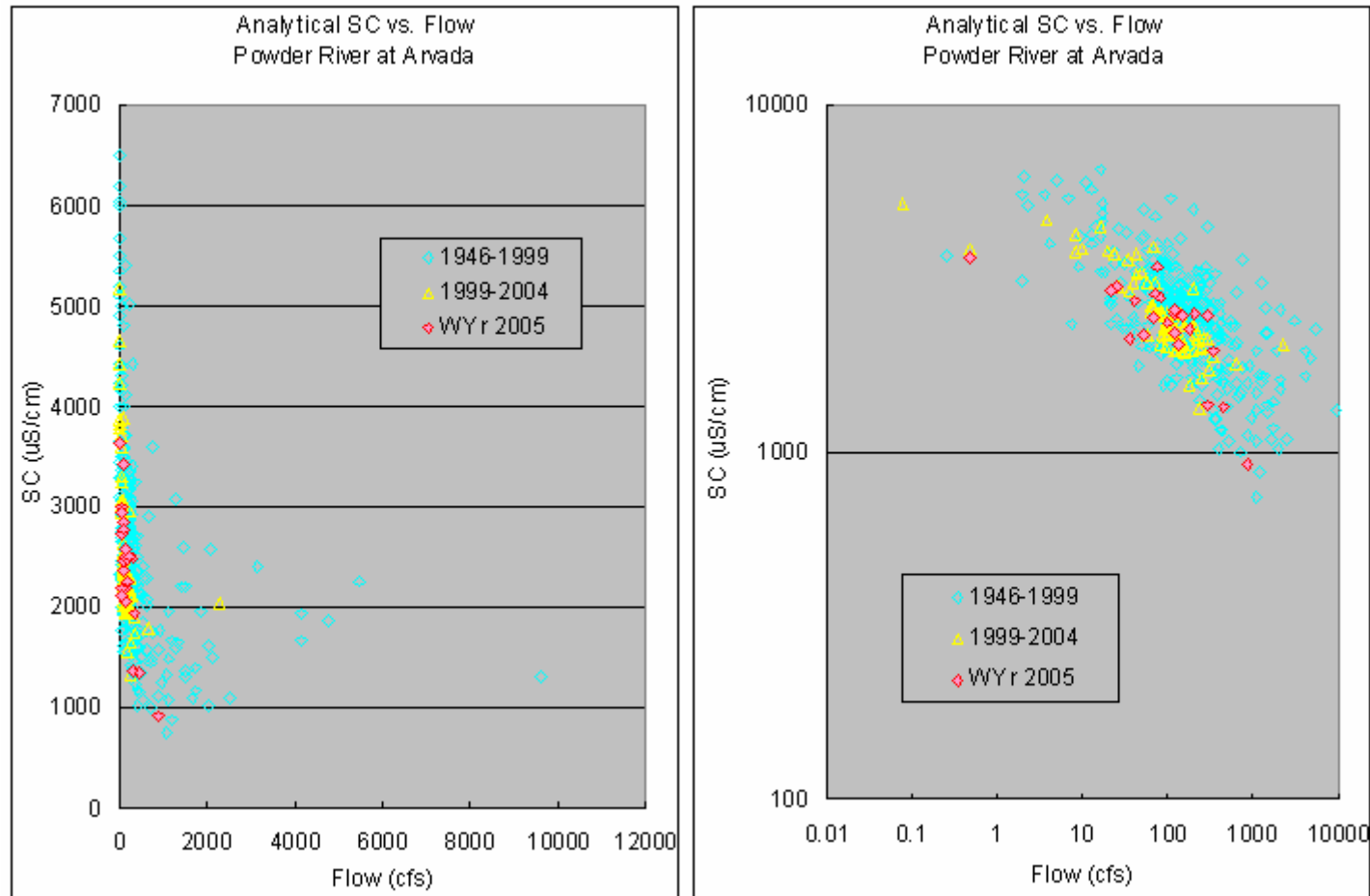


Figure 15 shows analytical SC vs. Flow data for water year 2005 for the Powder River at Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 16: Powder River at Arvada, WY

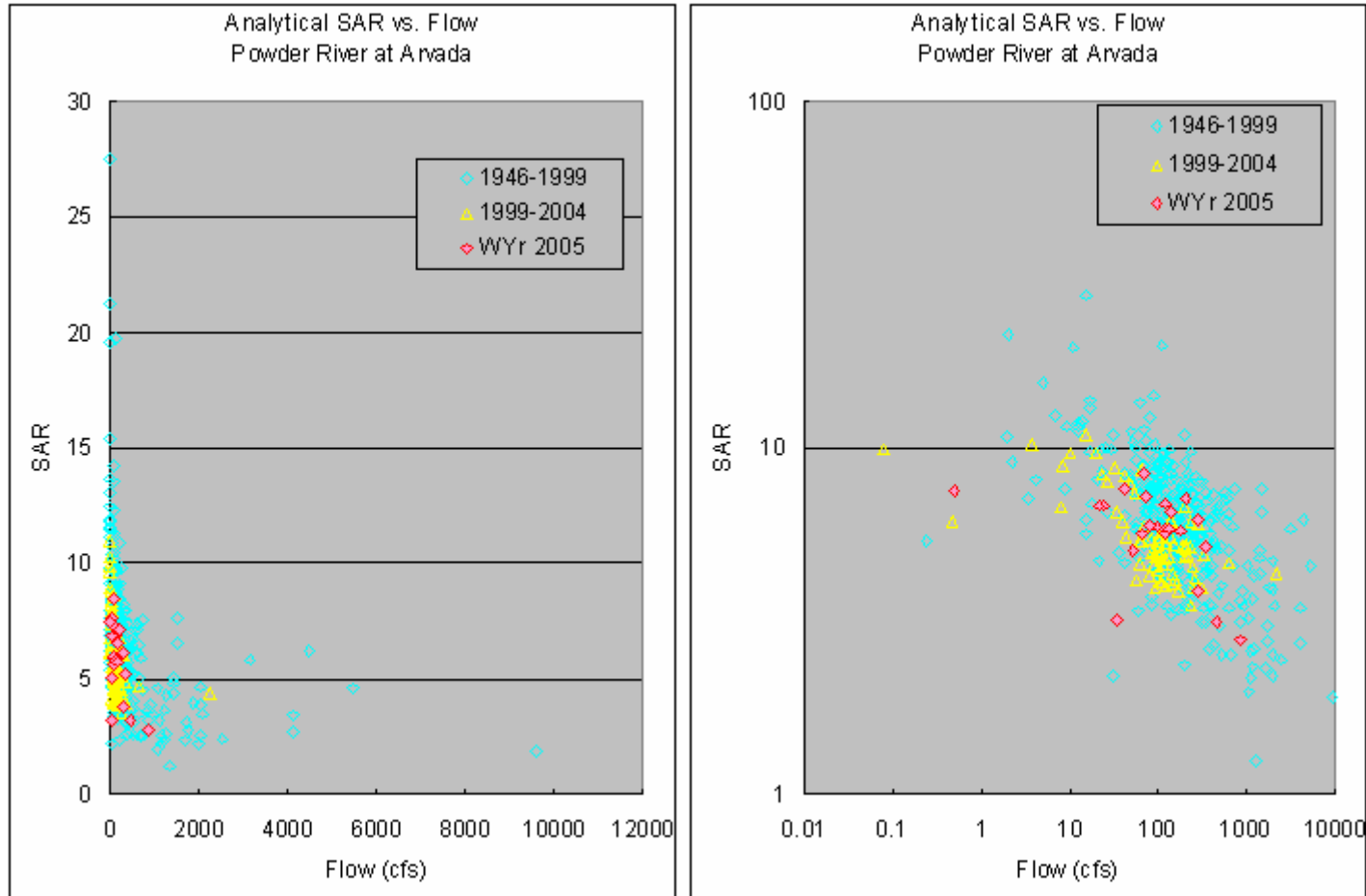


Figure 16 shows analytical SAR vs. Flow data for water year 2005 for the Powder River at Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 17: Powder River at Arvada, WY

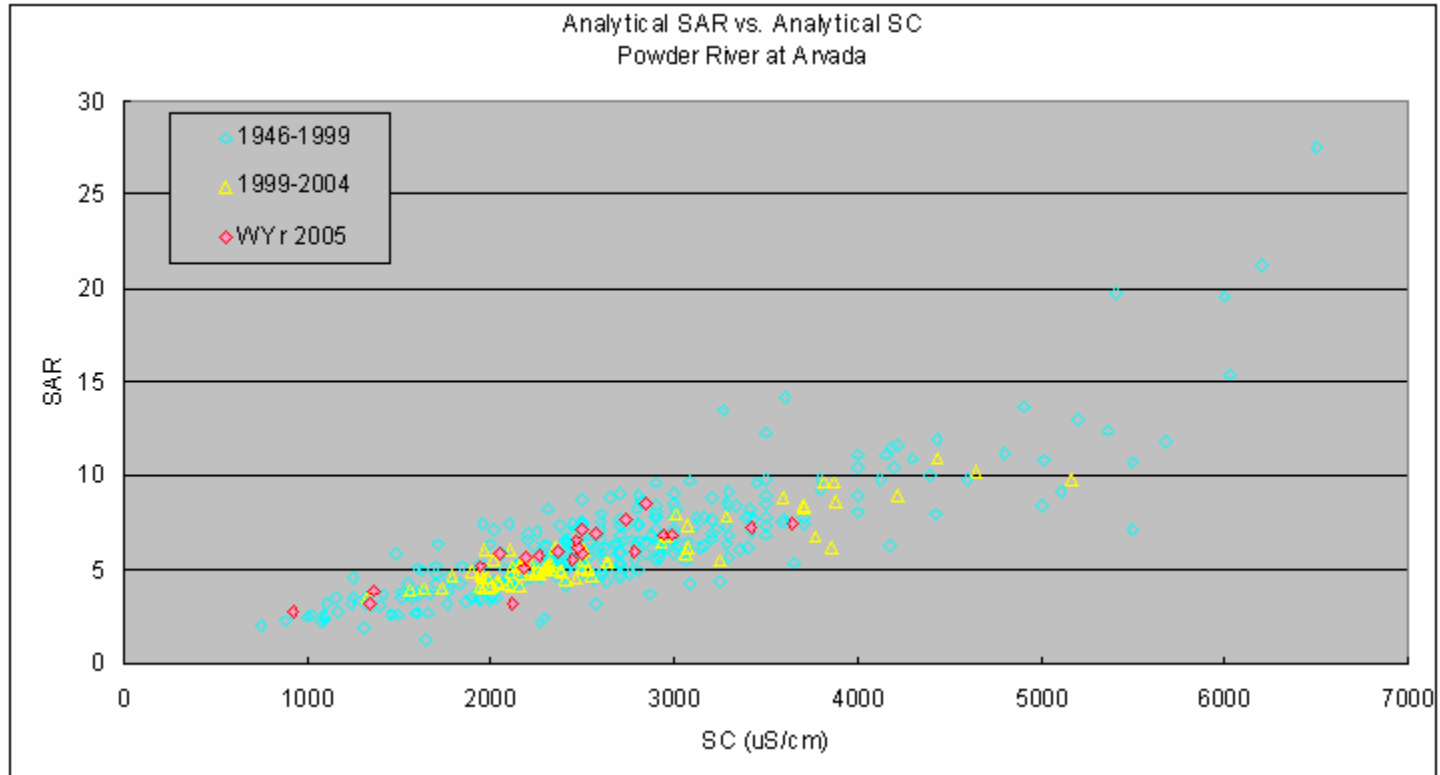


Figure 17 shows analytical SAR vs. analytical SC data for water year 2005 for the Powder River at Arvada. Historical SAR vs. SC data are also shown to place the data in context.

Figure 18: Powder River at Moorhead, MT

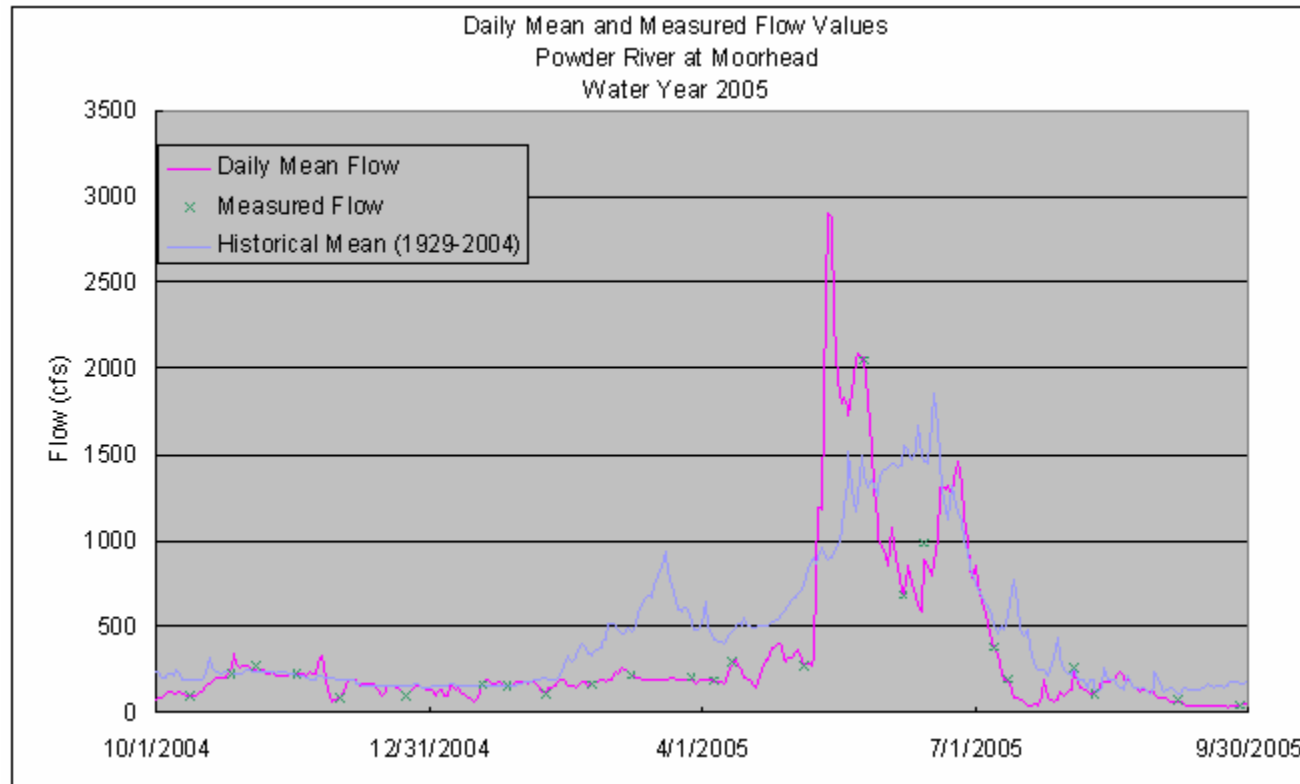


Figure 18 shows mean daily and field measurements of flow in a time series plot for water year 2005 for the Powder River at Moorhead. Mean daily flow values ranged from 27 to 2900 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 19: Powder River at Moorhead, MT

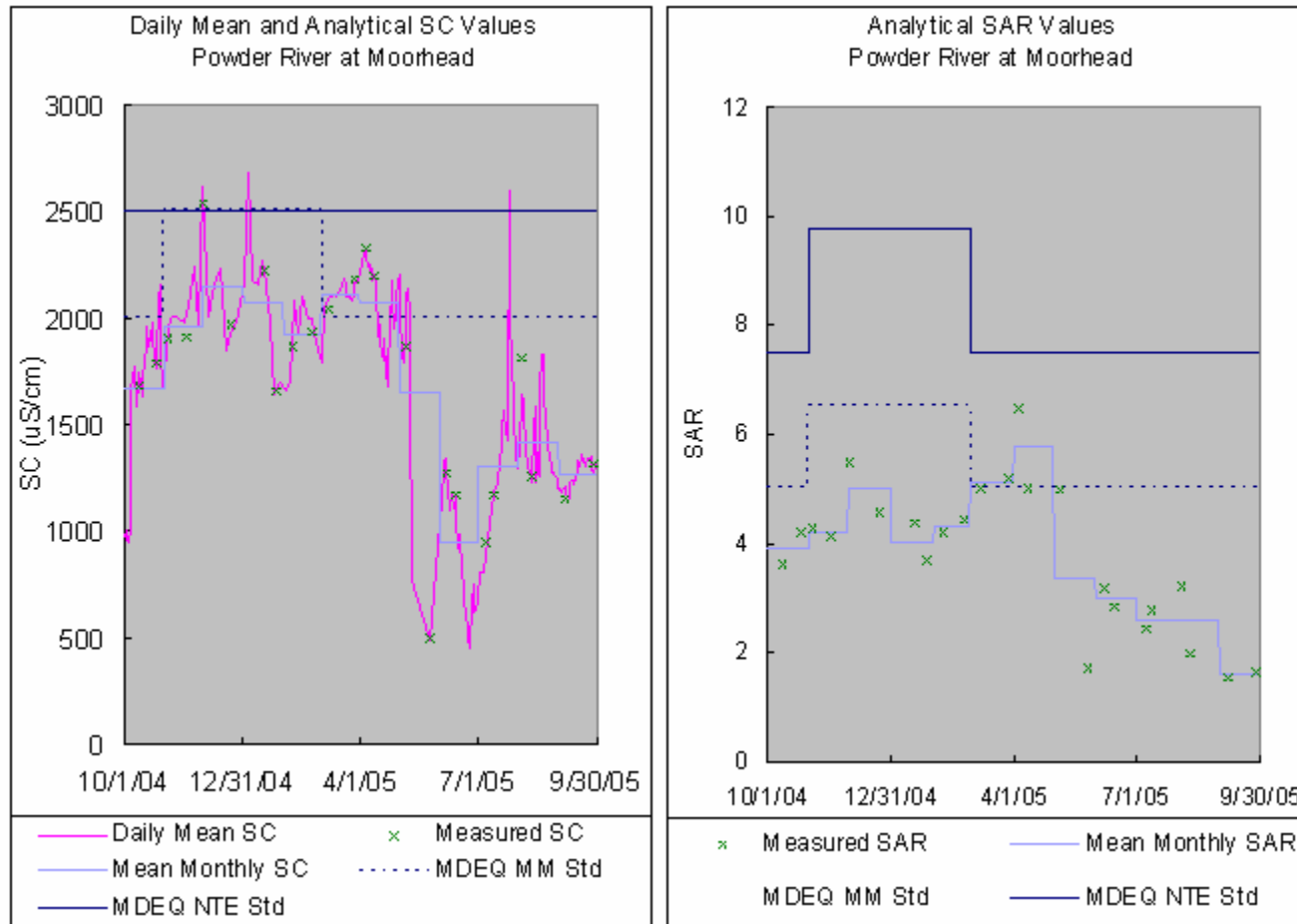


Figure 19 shows analytical and mean daily SC values (A) and analytical SAR values (B) values in time series plots for water year 2005 for the Powder River at Moorhead. Mean Monthly SC and SAR values are also shown. SC values ranged from 450 to 2680 uS/cm. SAR values ranged from 1.5 to 6.5. MDEQ standards are also displayed for comparison.

Figure 20: Powder River at Moorhead, MT

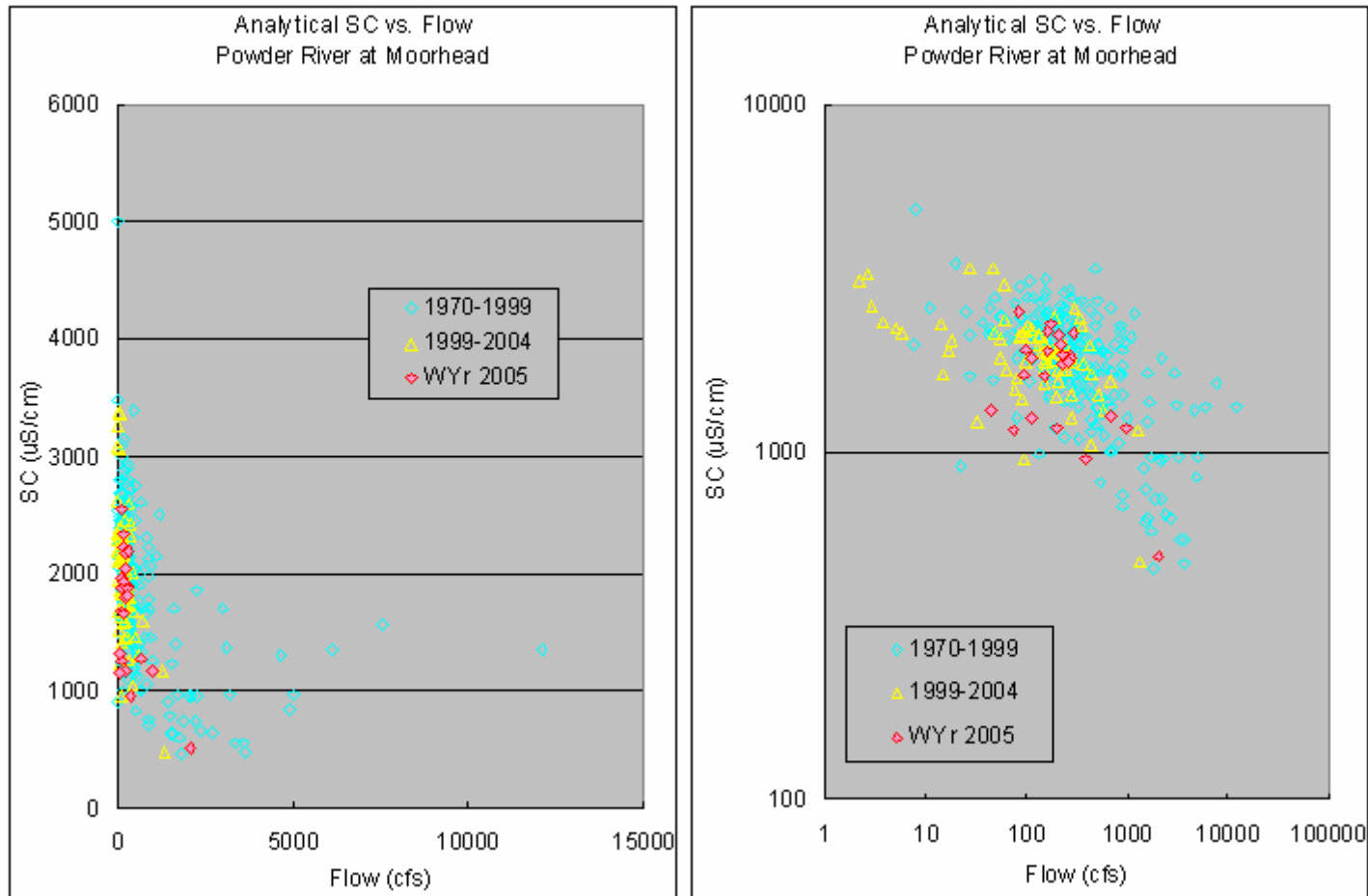


Figure 20 shows analytical SC vs. Flow data for water year 2005 for the Powder River at Moorhead. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 21: Powder River at Moorhead, MT

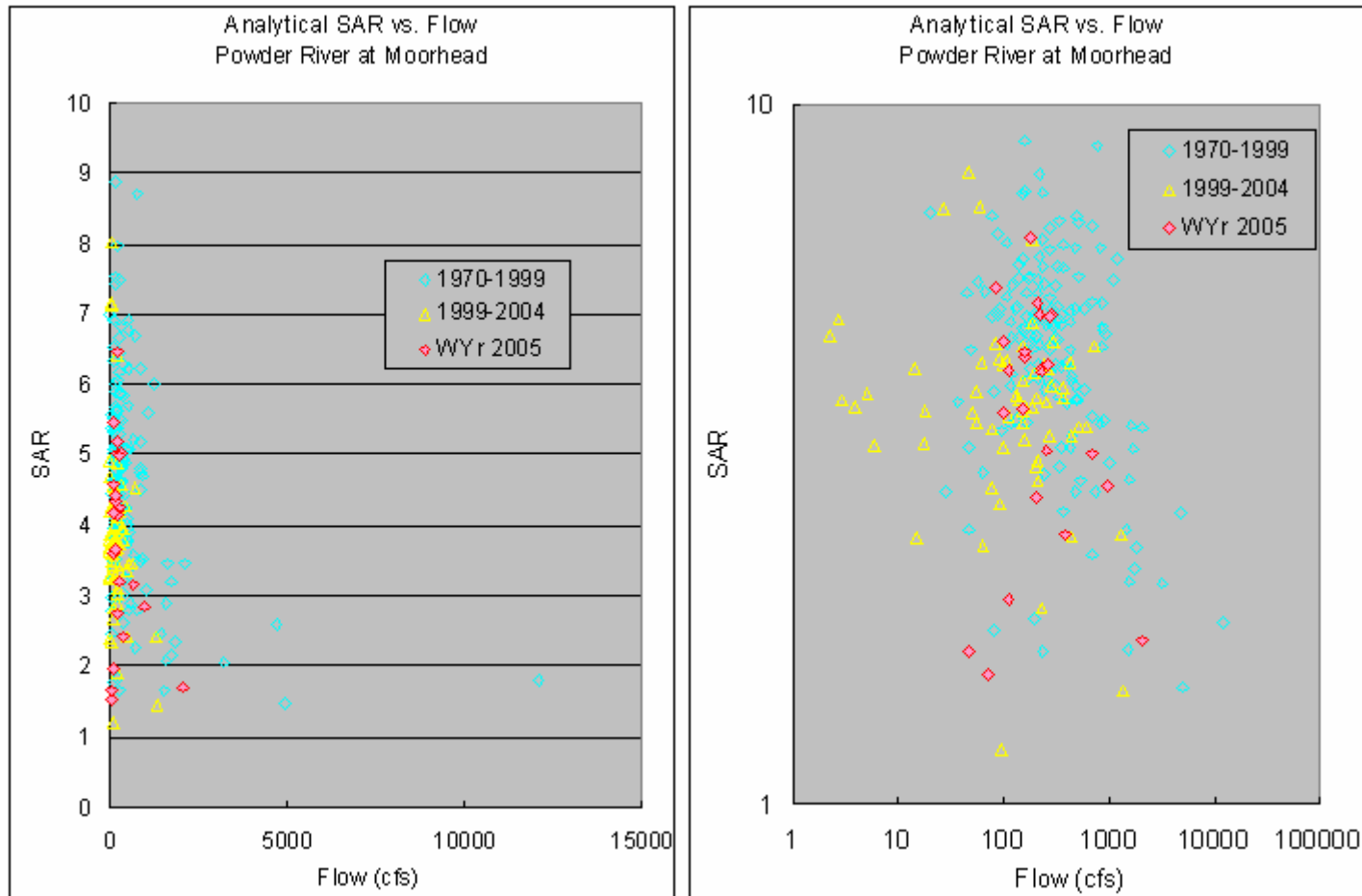


Figure 21 shows analytical SAR vs. Flow data for water year 2005 for the Powder River at Moorhead. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 22: Powder River at Moorhead, MT

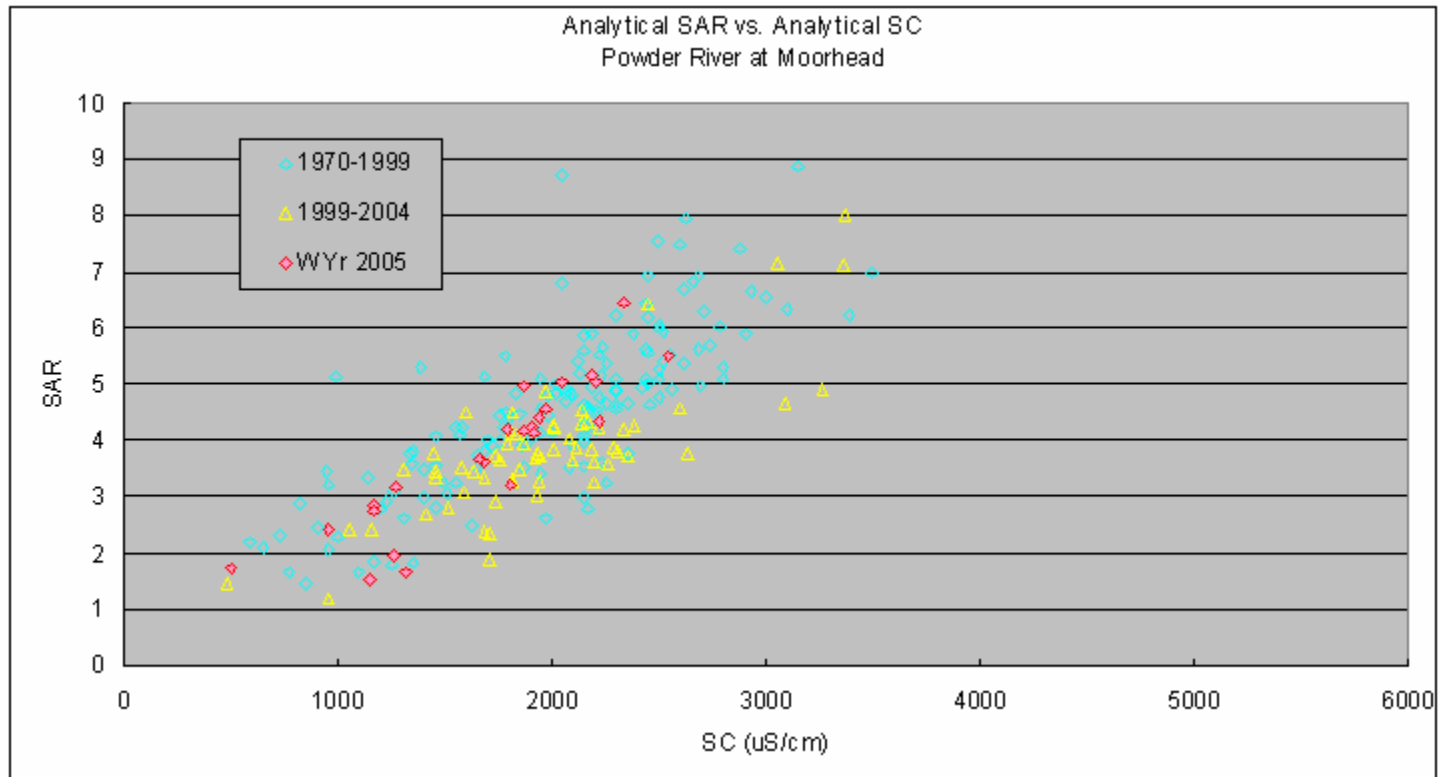


Figure 22 shows analytical SAR vs. analytical SC data for water year 2005 for the Powder River at Moorhead. Historical SAR vs. SC data are also shown to place the data in context.

Figure 23: Powder River near Locate, MT

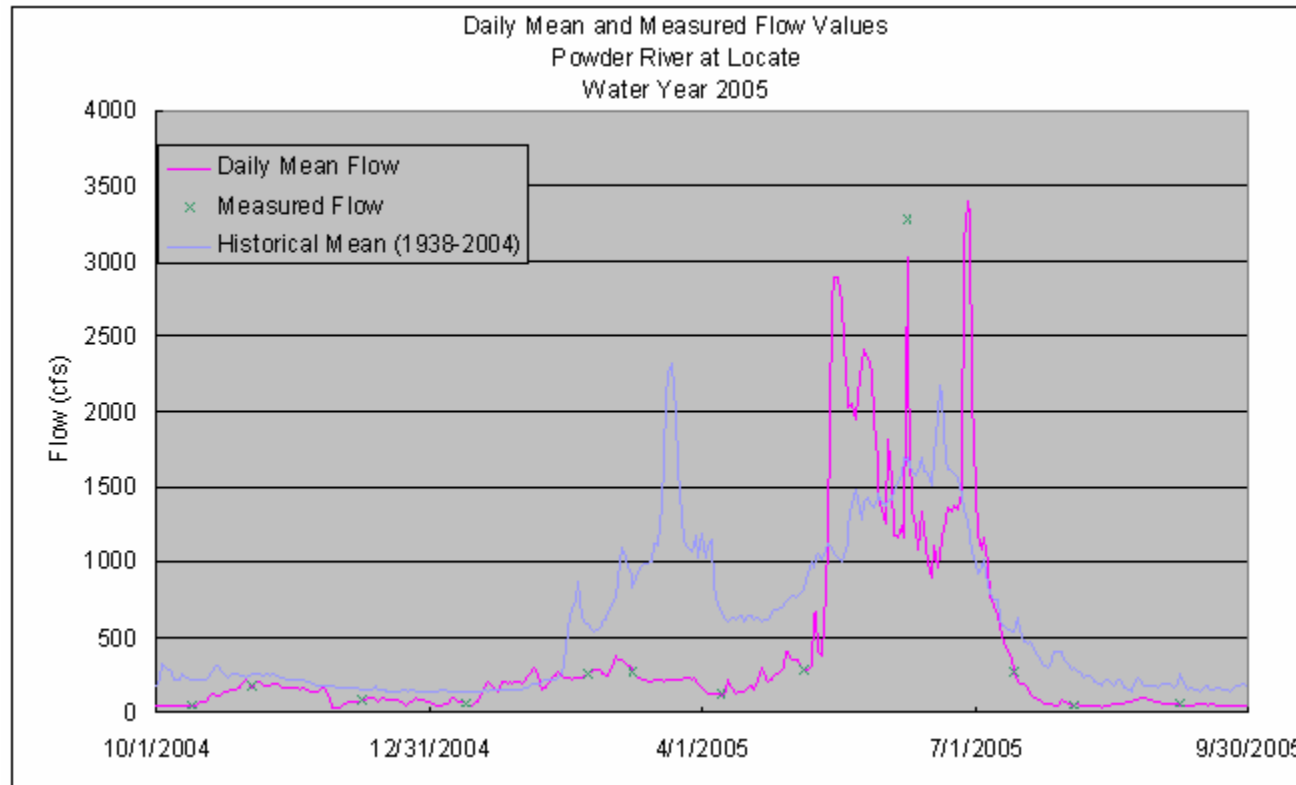


Figure 23 shows mean daily and field measurements of flow in a time series plot for water year 2005 for the Powder River near Locate. Mean daily flow values ranged from 25 to 3390 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 24: Powder River near Locate, MT

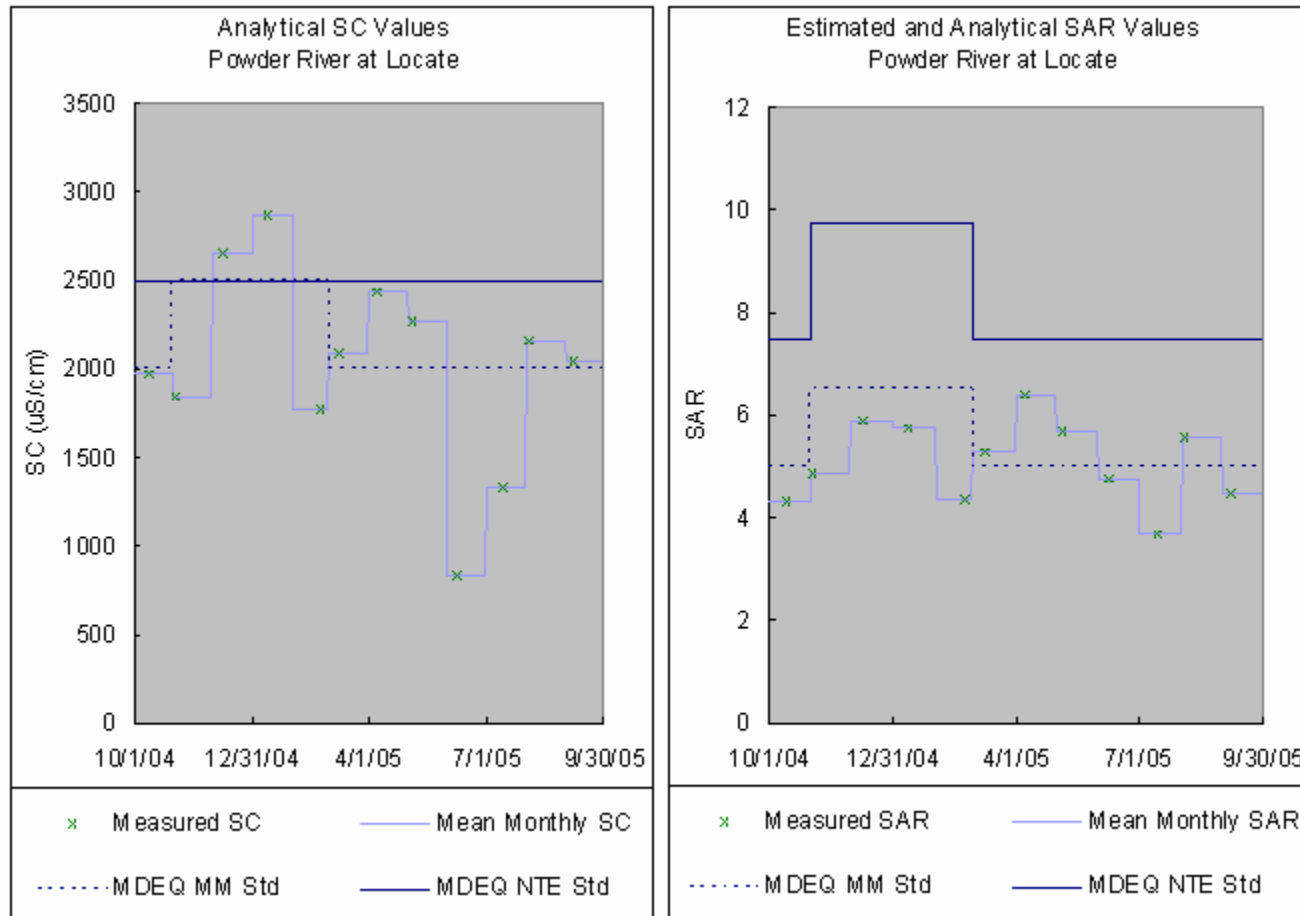


Figure 24 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2005 for the Powder River near Locate. Mean Monthly SC and SAR values are also shown. SC values ranged from 838 to 2870 uS/cm. SAR values ranged from 3.7 to 6.4. MDEQ standards are also displayed for comparison.

Figure 25: Powder River near Locate, MT

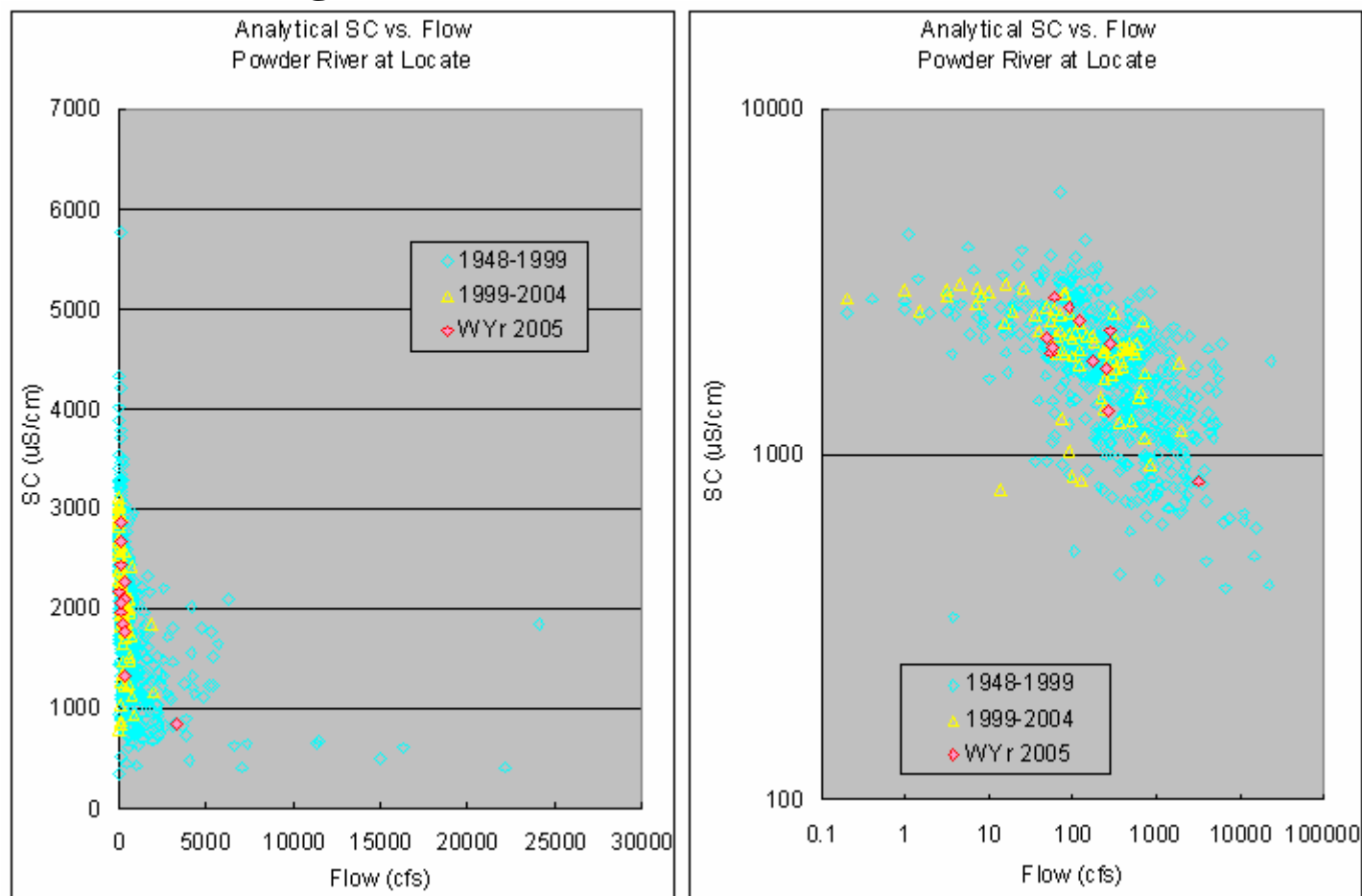


Figure 25 shows analytical SC vs. Flow data for water year 2005 for the Powder River near Locate. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 26: Powder River near Locate, MT

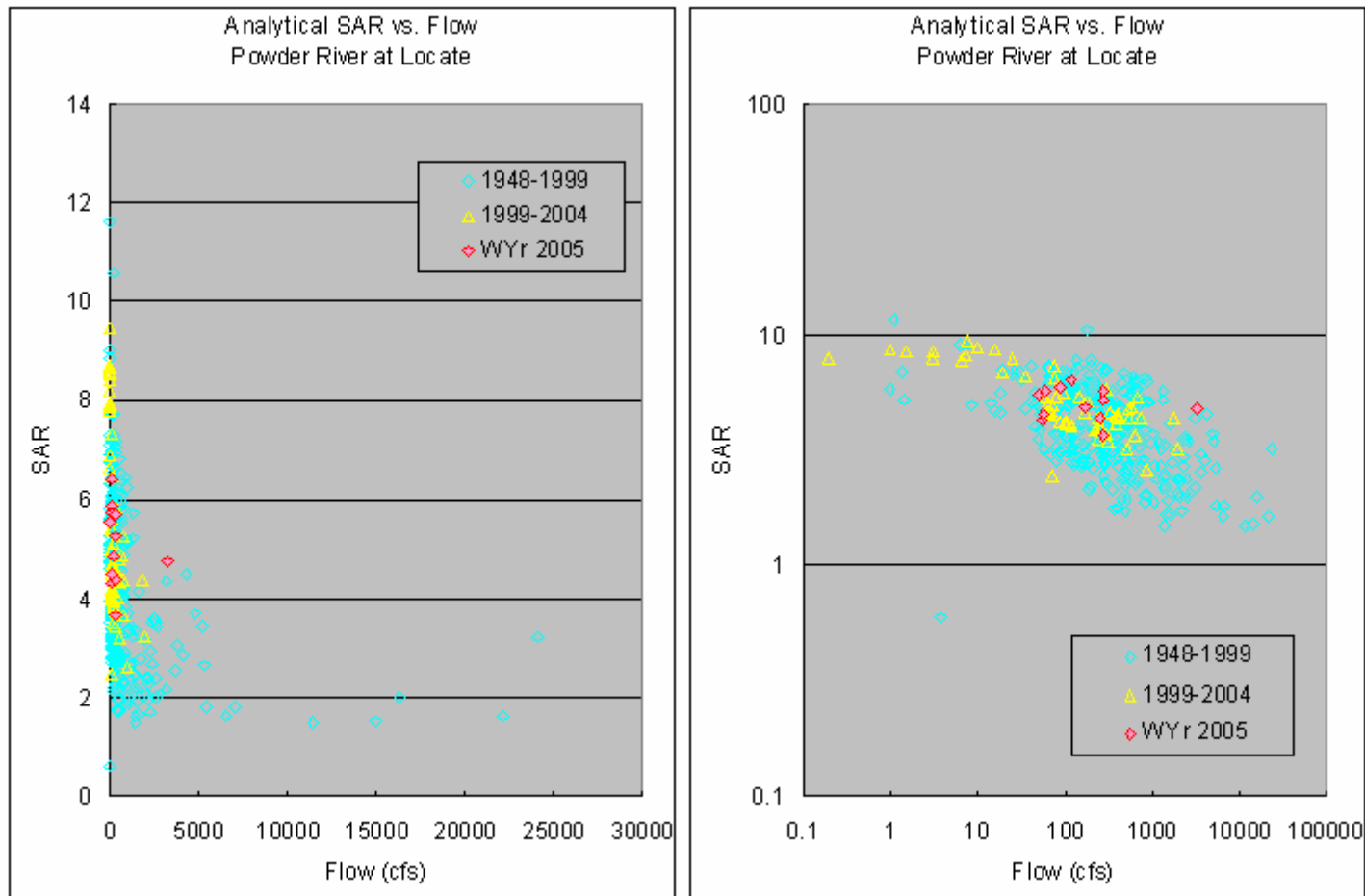


Figure 26 shows analytical SAR vs. Flow data for water year 2005 for the Powder River near Locate. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 27: Powder River near Locate, MT

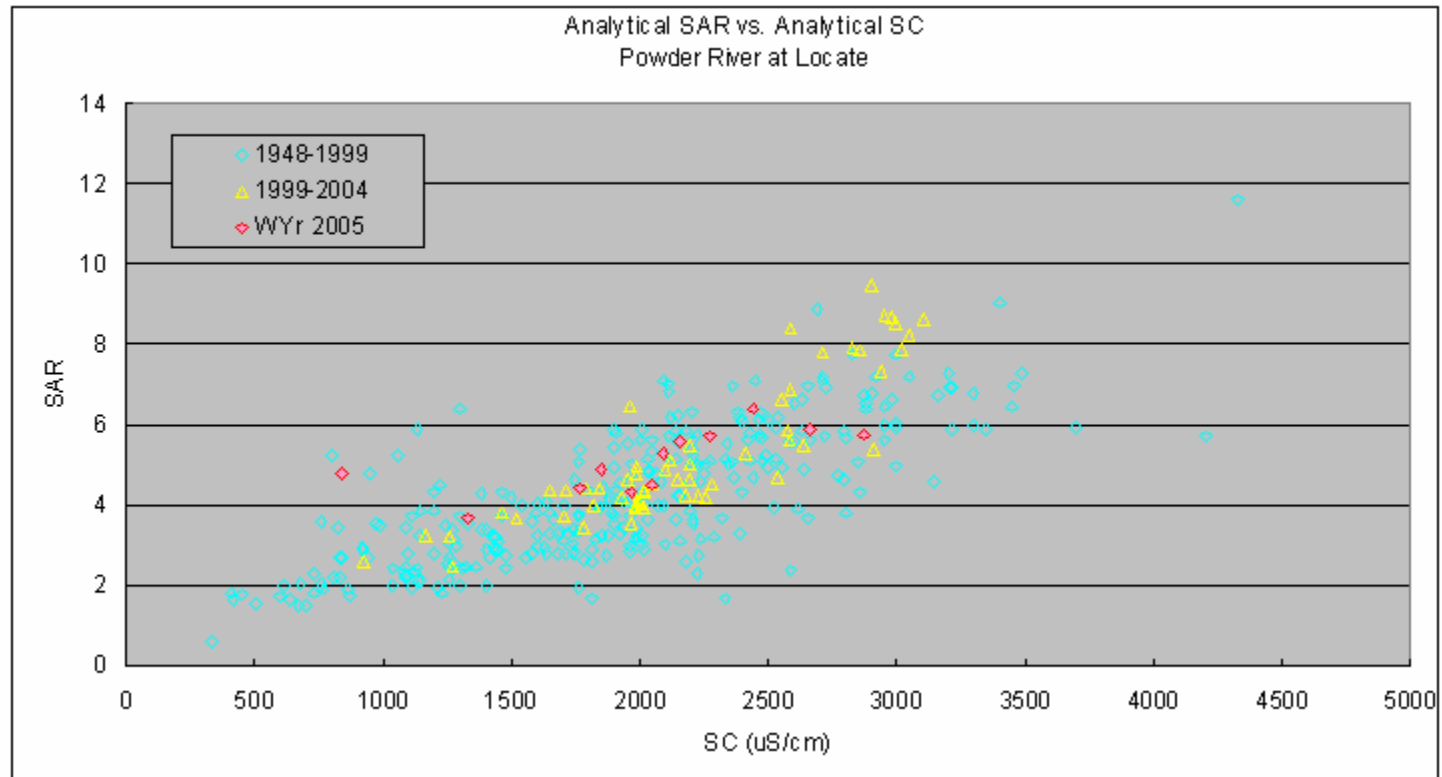


Figure 27 shows analytical SAR vs. analytical SC data for water year 2005 for the Powder River near Locate. Historical SAR vs. SC data are also shown to place the data in context.

Figure 28: Crazy Woman Creek at Upper Station, near Arvada, WY

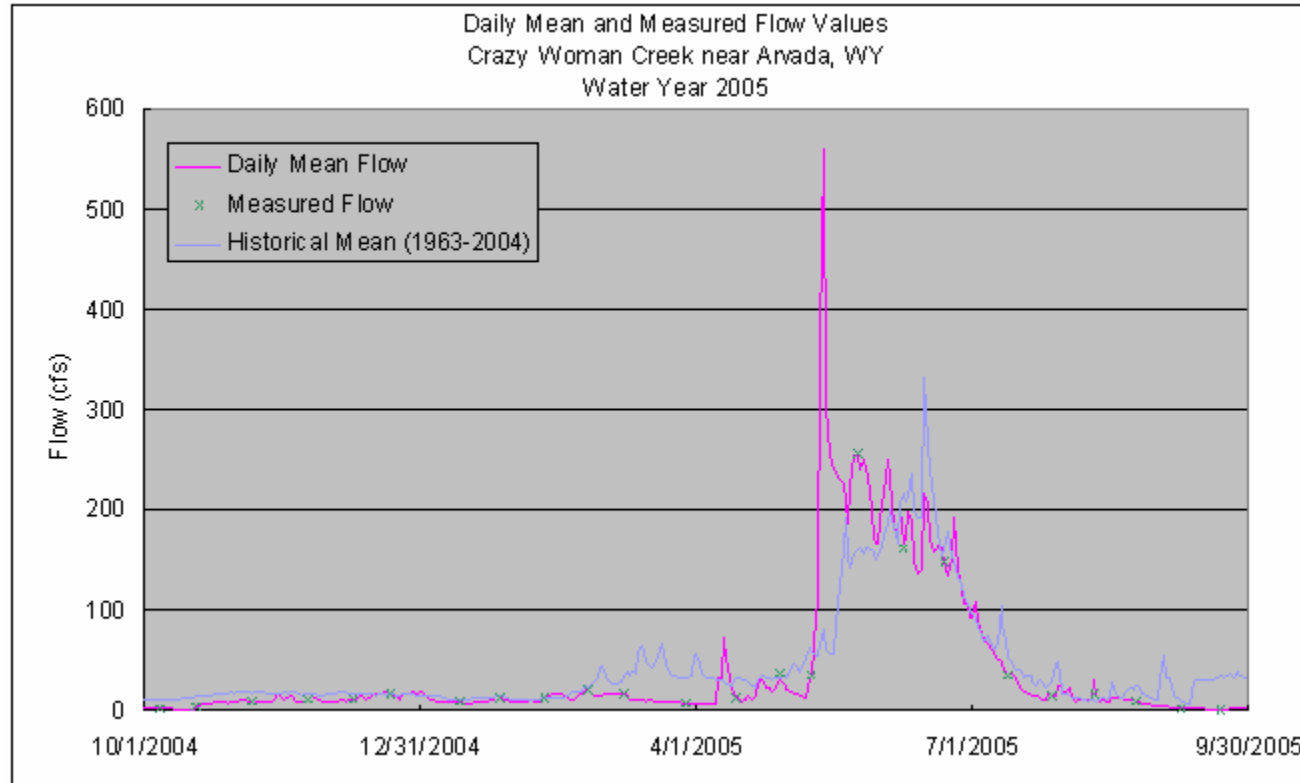


Figure 28 shows mean daily and field measurements of flow in a time series plot for water year 2005 for Crazy Woman near Arvada. Mean daily flow values ranged from 0.36 to 559 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 29: Crazy Woman Creek at Upper Station, near Arvada, WY

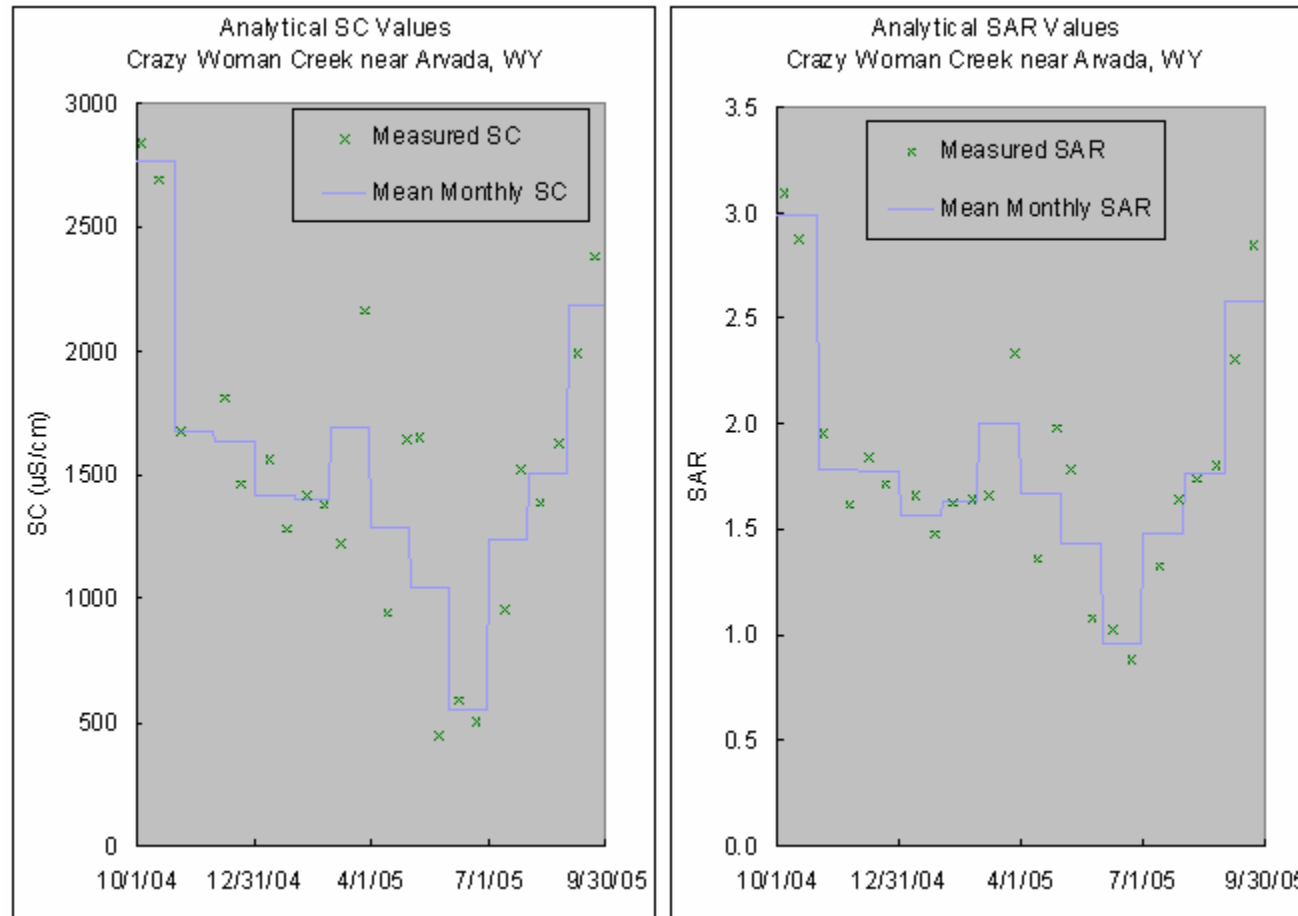


Figure 29 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2005 for Crazy Woman Creek near Arvada. Mean Monthly SC and SAR values are also shown. SC values ranged from 442 to 2840 uS/cm. SAR values ranged from 0.9 to 3.1.

Figure 30: Crazy Woman Creek at Upper Station, near Arvada, WY

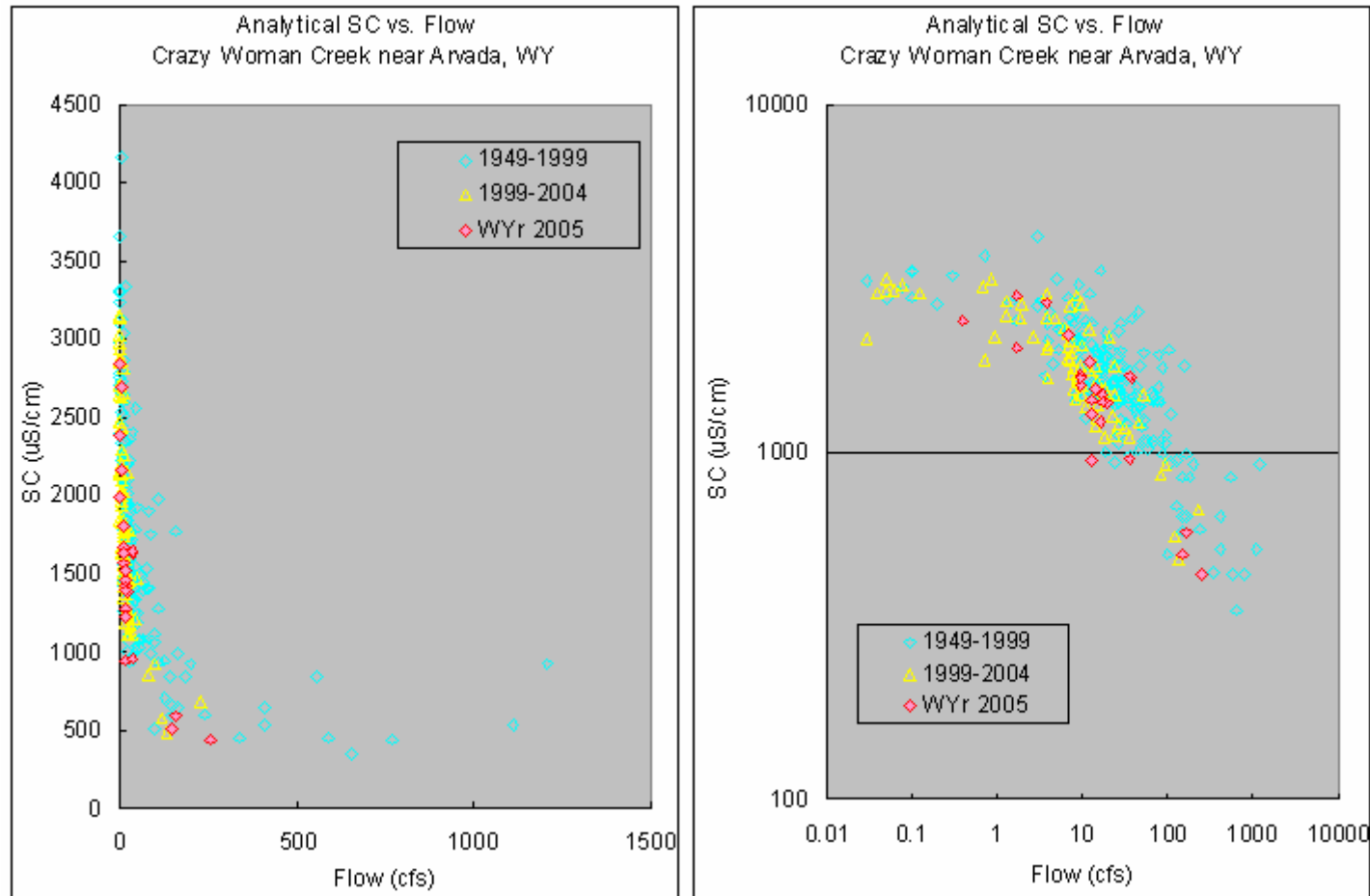


Figure 30 shows analytical SC vs. Flow data for water year 2005 for Crazy Woman near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 31: Crazy Woman Creek at Upper Station, near Arvada, WY

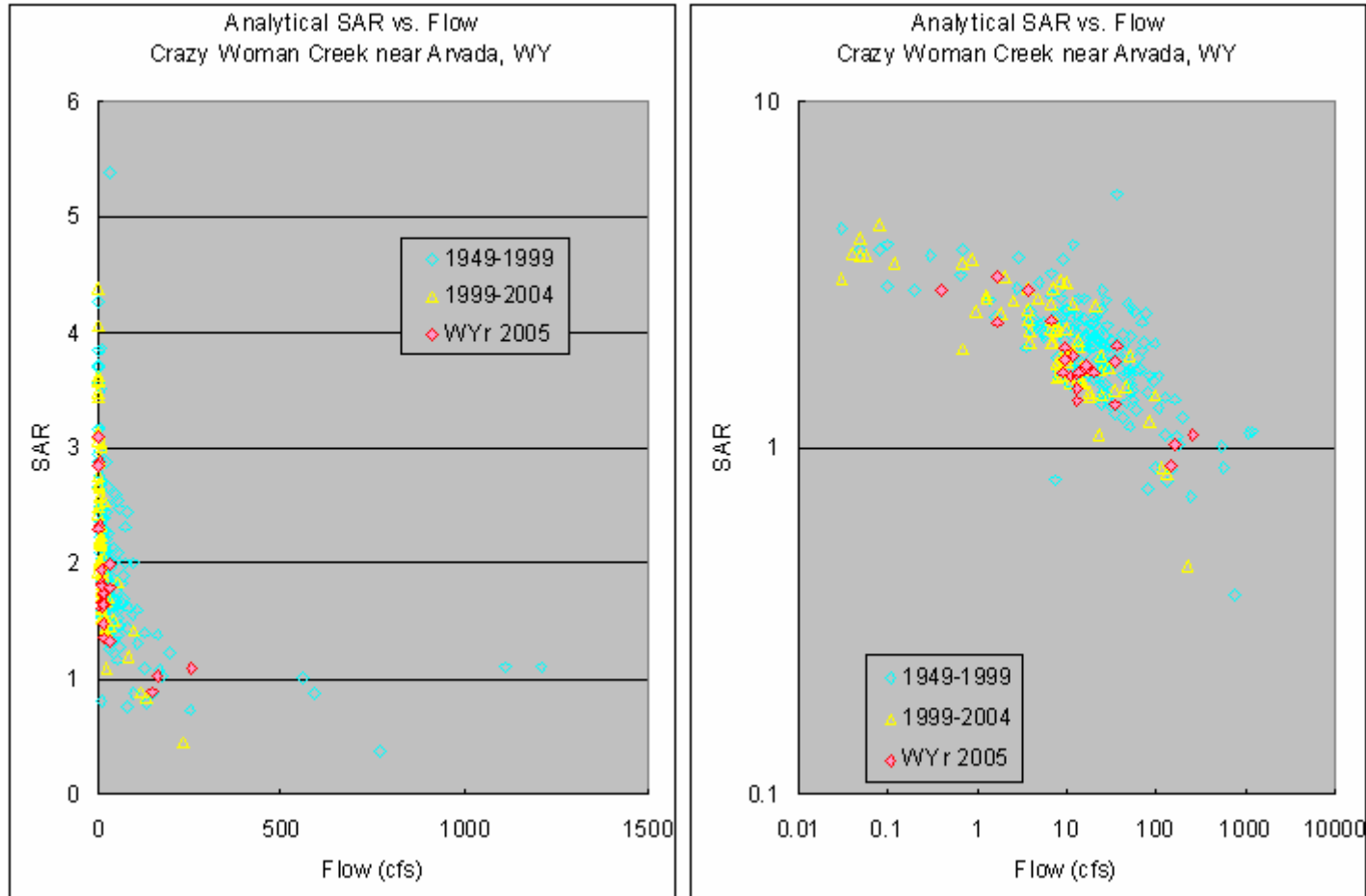


Figure 31 shows analytical SAR vs. Flow data for water year 2005 for Crazy Woman near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 32: Crazy Woman Creek at Upper Station, near Arvada, WY

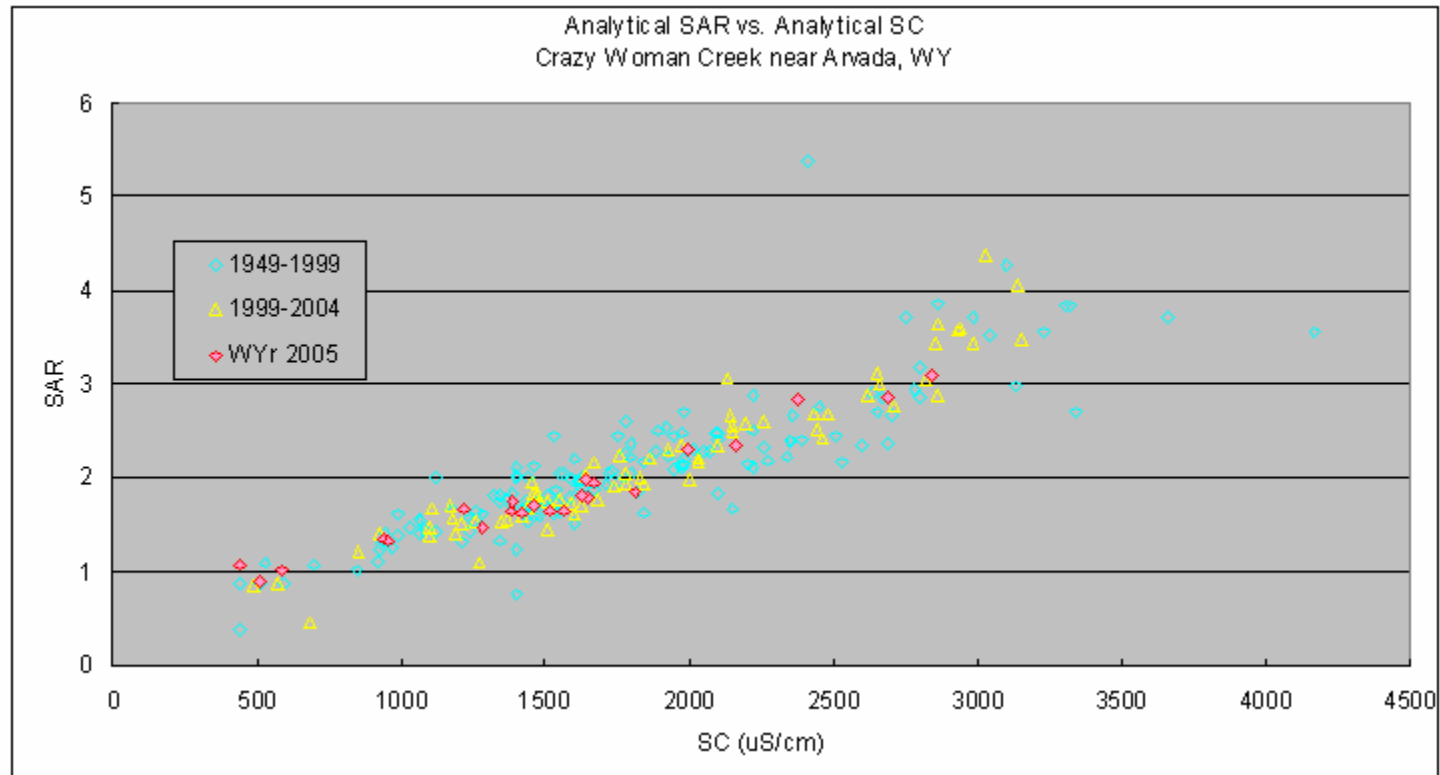


Figure 32 shows analytical SAR vs. analytical SC data for water year 2005 for Crazy Woman near Arvada. Historical SAR vs. SC data are also shown to place the data in context.

Figure 33: Clear Creek near Arvada, WY

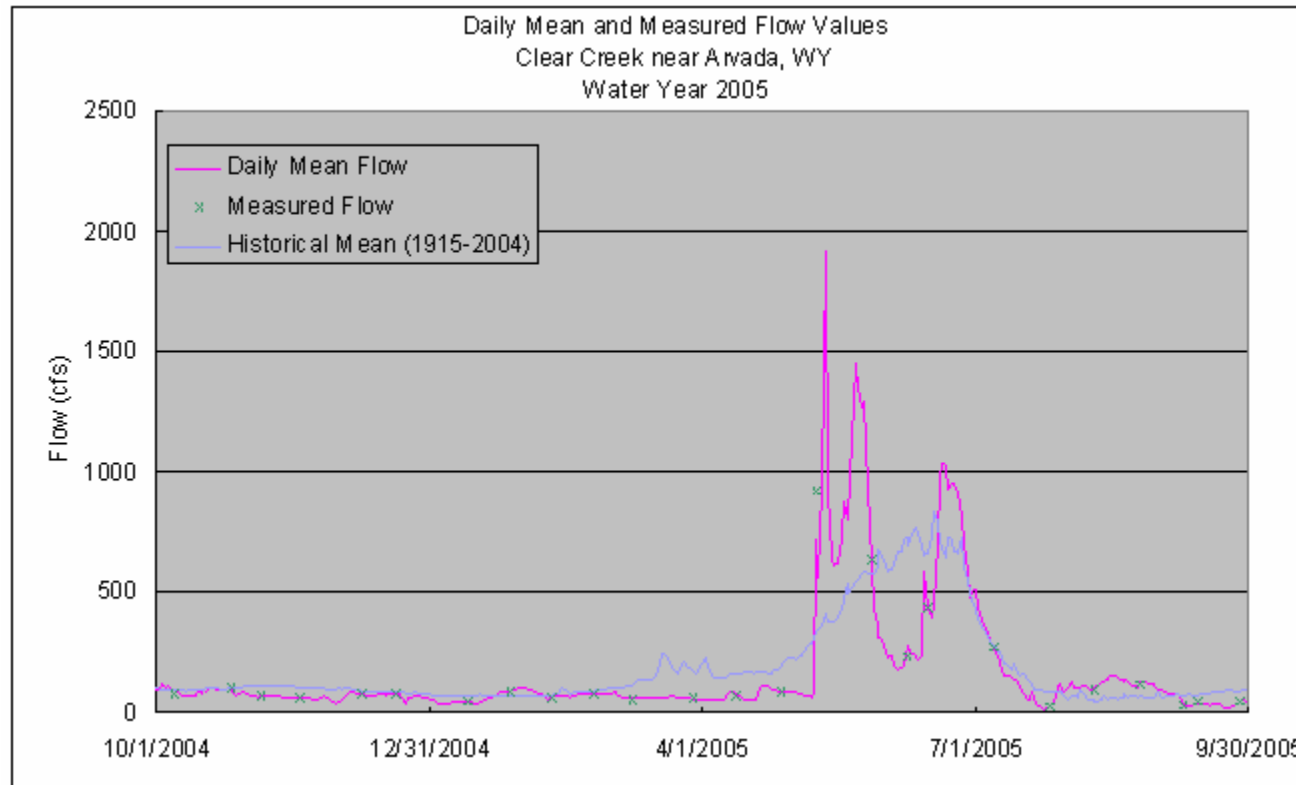


Figure 33 shows mean daily and field measurements of flow in a time series plot for water year 2005 for Clear Creek near Arvada. Mean daily flow values ranged from 11 to 1910 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 34: Clear Creek near Arvada, WY

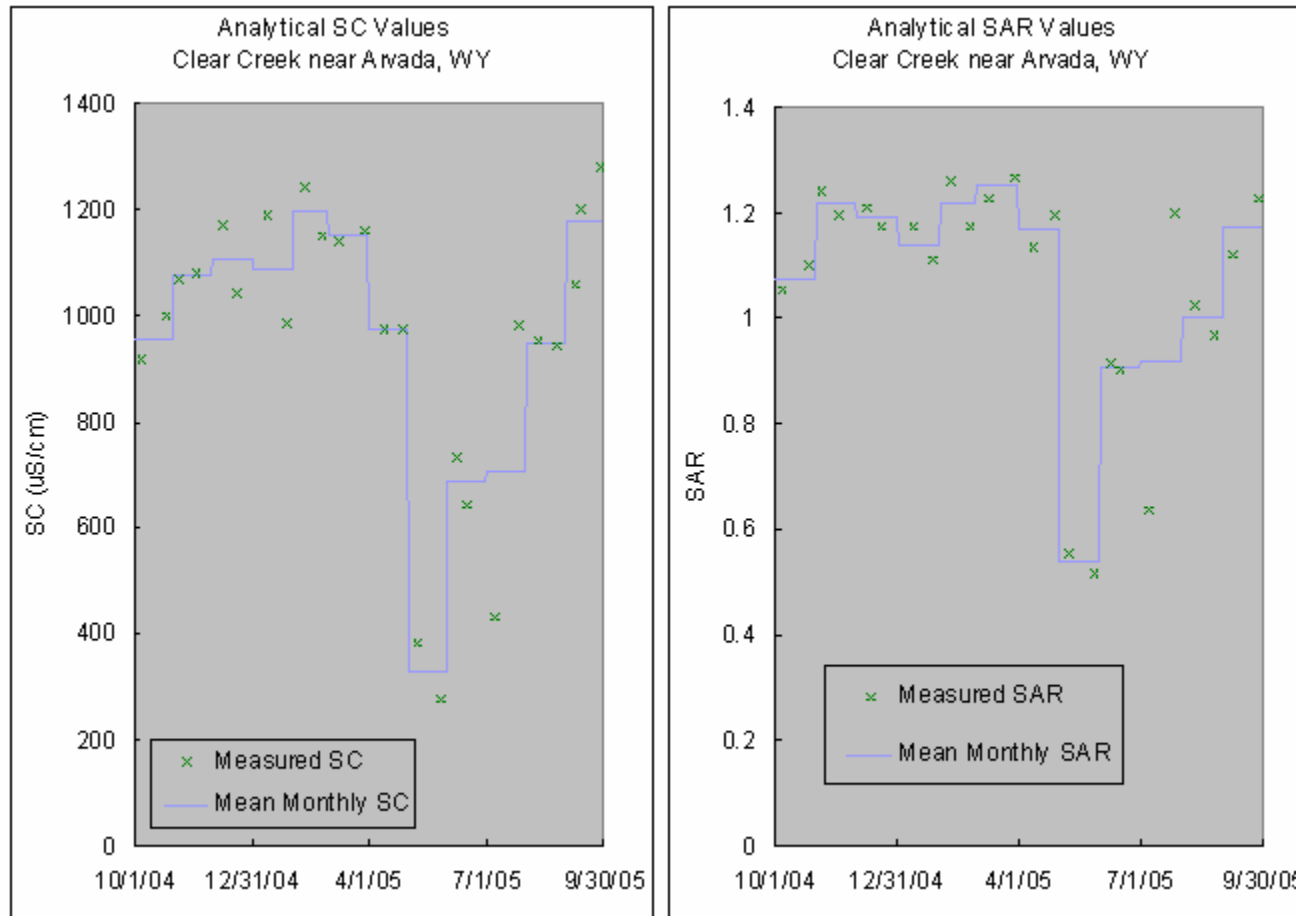


Figure 34 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2005 for Clear Creek near Arvada. Mean Monthly SC and SAR values are also shown. SC values ranged from 279 to 1280 uS/cm. SAR values ranged from 0.5 to 1.3.

Figure 35: Clear Creek near Arvada, WY

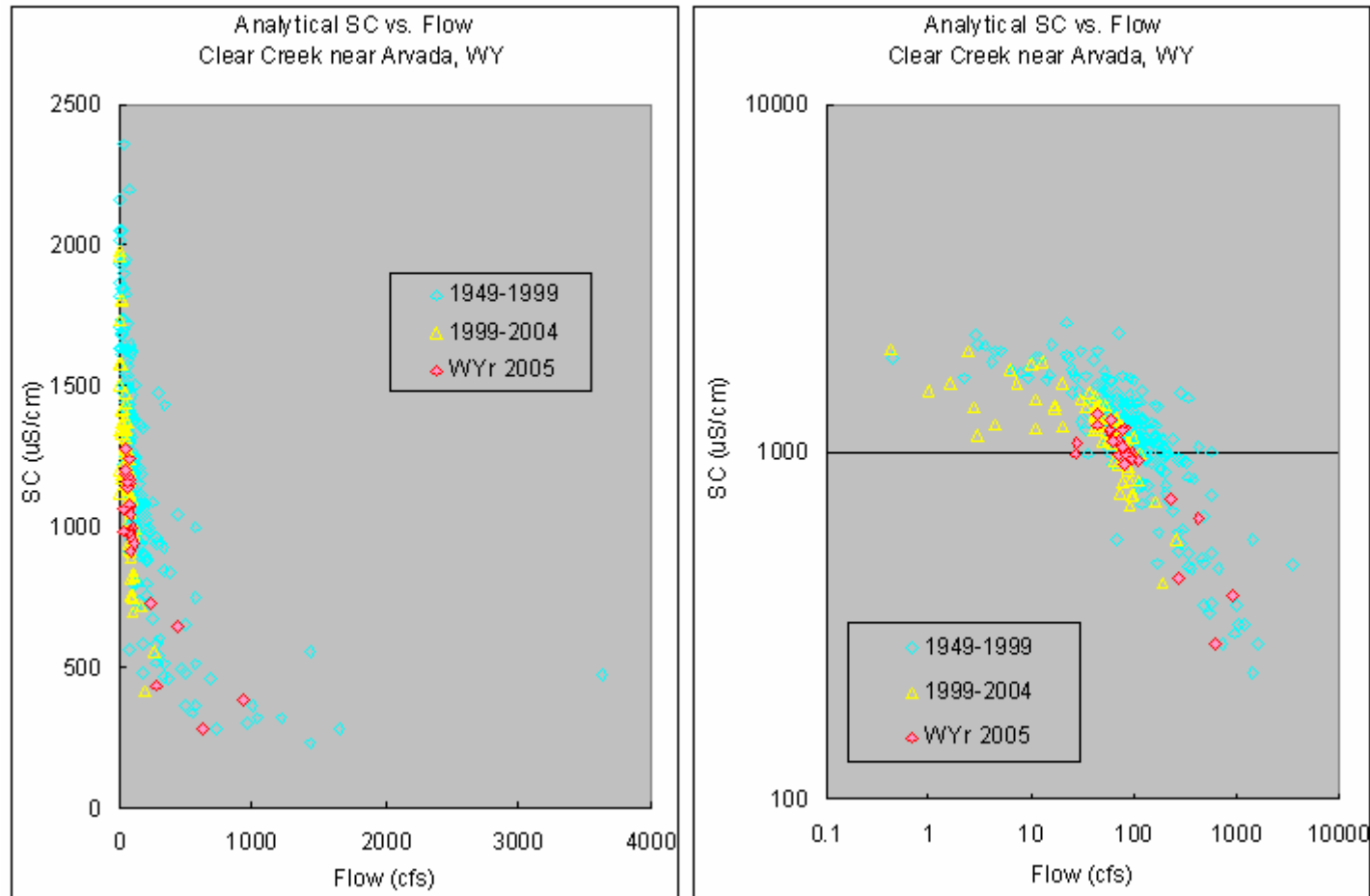


Figure 35 shows analytical SC vs. Flow data for water year 2005 for Clear Creek near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 36: Clear Creek near Arvada, WY

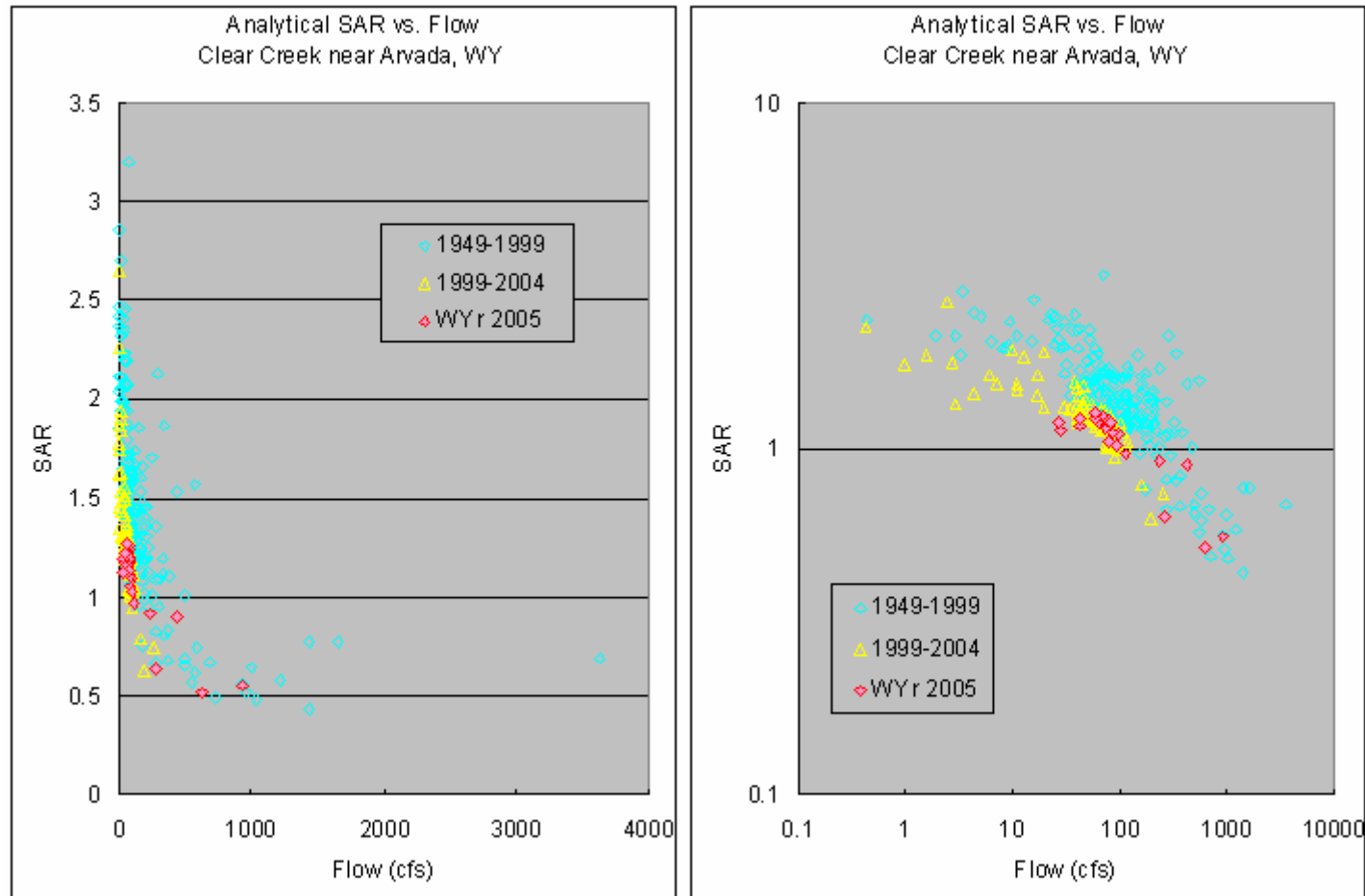


Figure 36 shows analytical SAR vs. Flow data for water year 2005 for Clear Creek near Arvada. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 37: Clear Creek near Arvada, WY

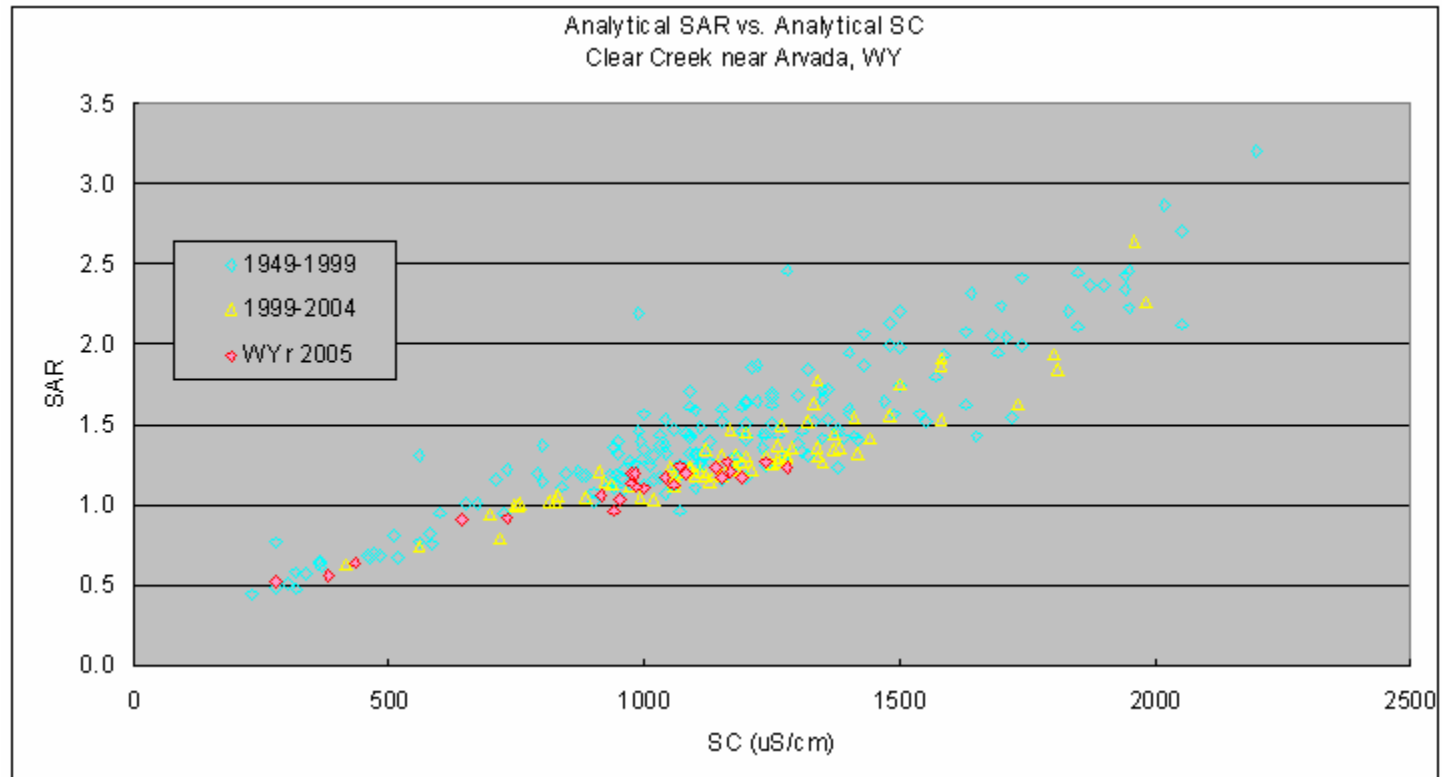


Figure 37 shows analytical SAR vs. analytical SC data for water year 2005 for Clear Creek near Arvada. Historical SAR vs. SC data are also shown to place the data in context.

Figure 38: Little Powder River above Dry Creek, near Weston, WY

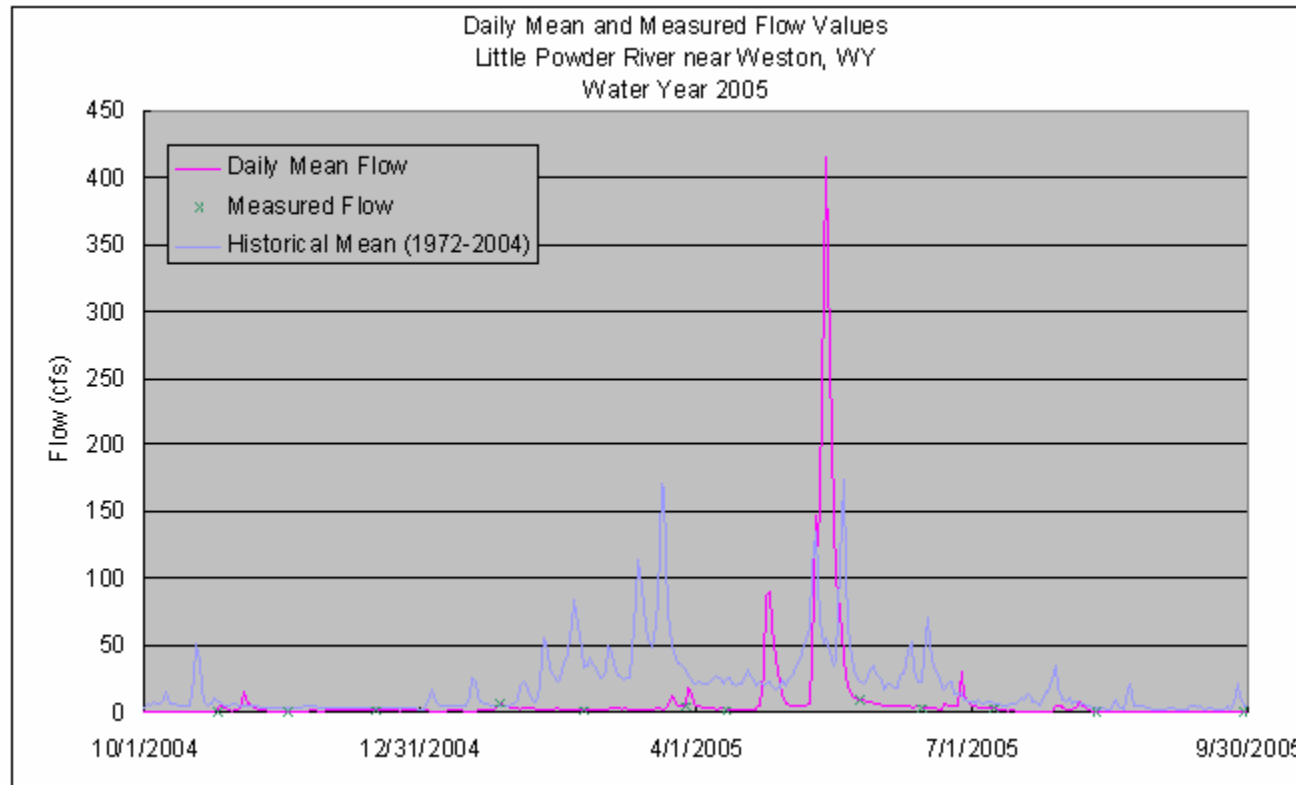


Figure 38 shows mean daily and field measurements of flow in a time series plot for water year 2005 for the Little Powder River near Weston. Mean daily flow values ranged from 0 to 415 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 39: Little Powder River above Dry Creek, near Weston, WY

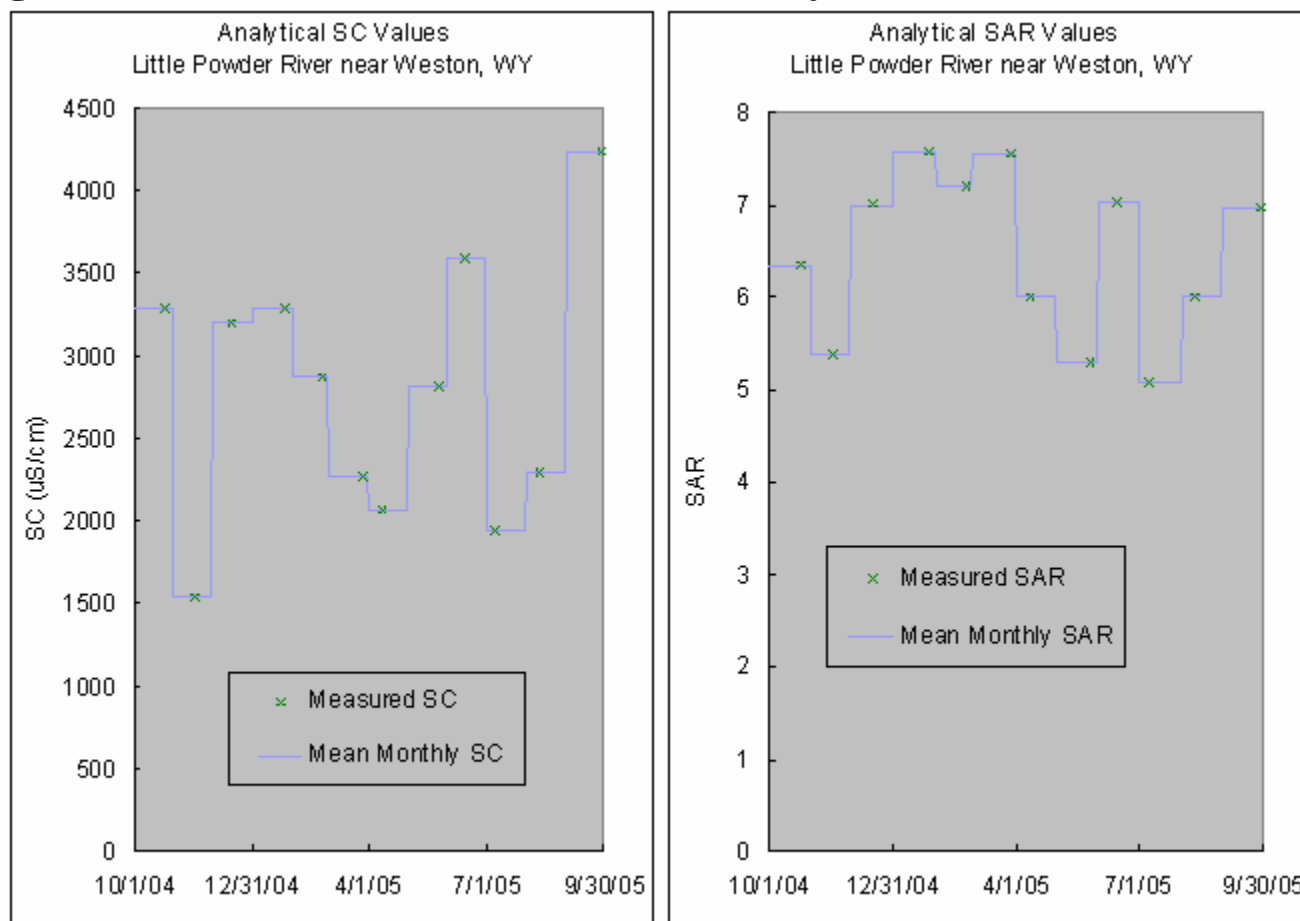


Figure 39 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2005 for the Little Powder River near Weston. Mean Monthly SC and SAR values are also shown. SC values ranged from 1540 to 4240 uS/cm. SAR values ranged from 5.1 to 7.6.

Figure 40: Little Powder River above Dry Creek, near Weston, WY

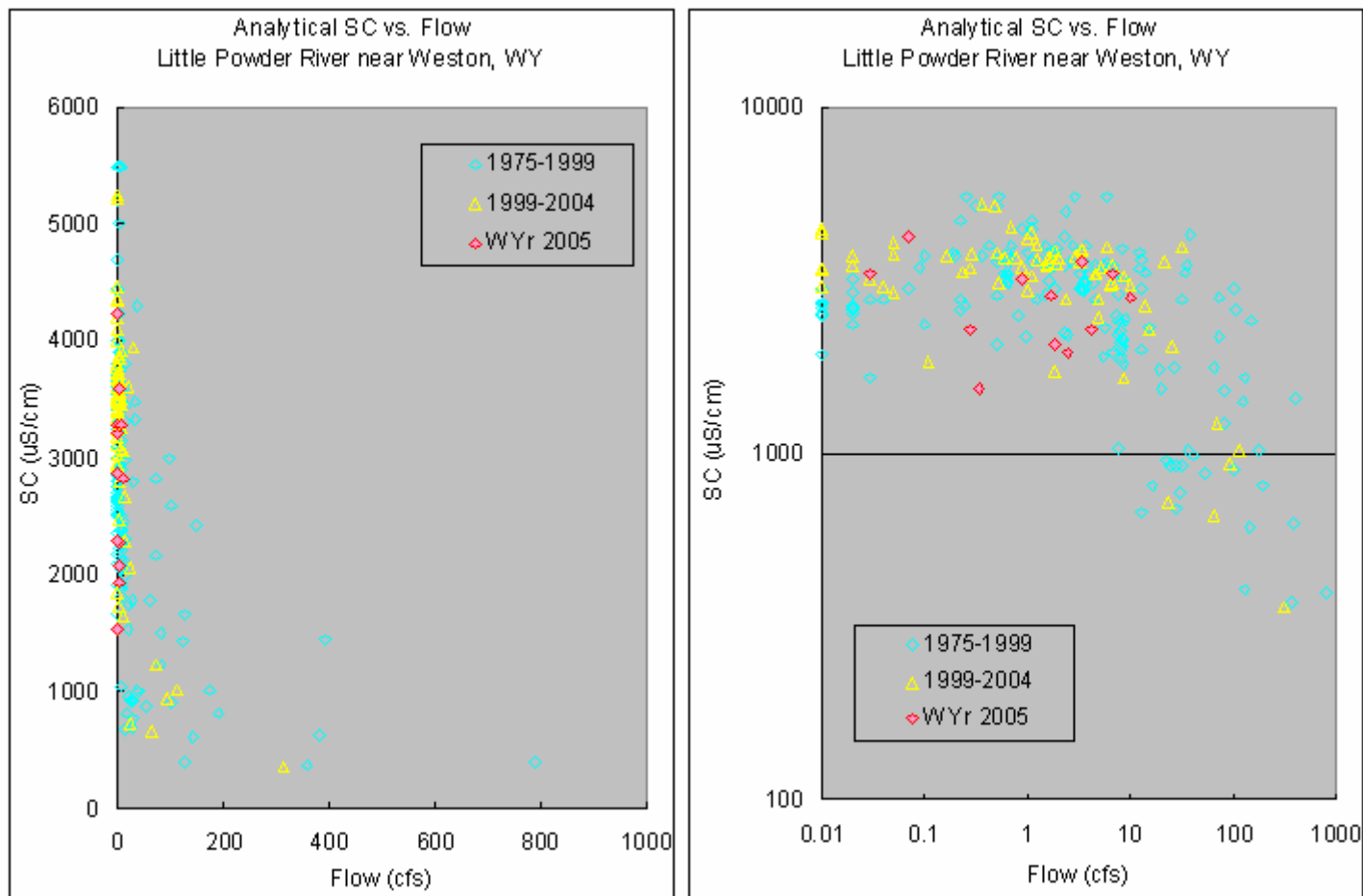


Figure 40 shows analytical SC vs. Flow data for water year 2005 for the Little Powder River near Weston. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 41: Little Powder River above Dry Creek, near Weston, WY

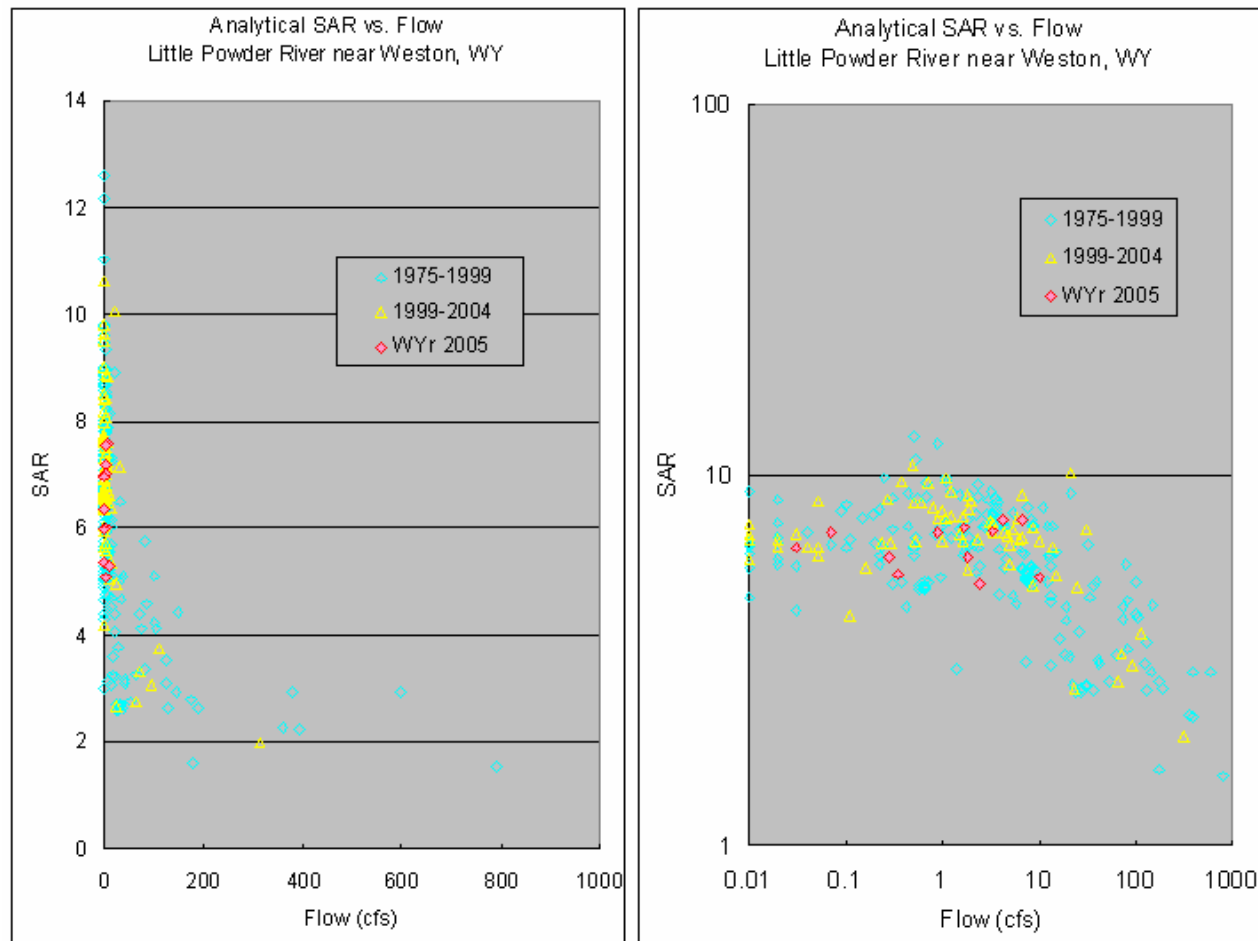


Figure 41 shows analytical SAR vs. Flow data for water year 2005 for the Little Powder River near Weston. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 42: Little Powder River above Dry Creek, near Weston, WY

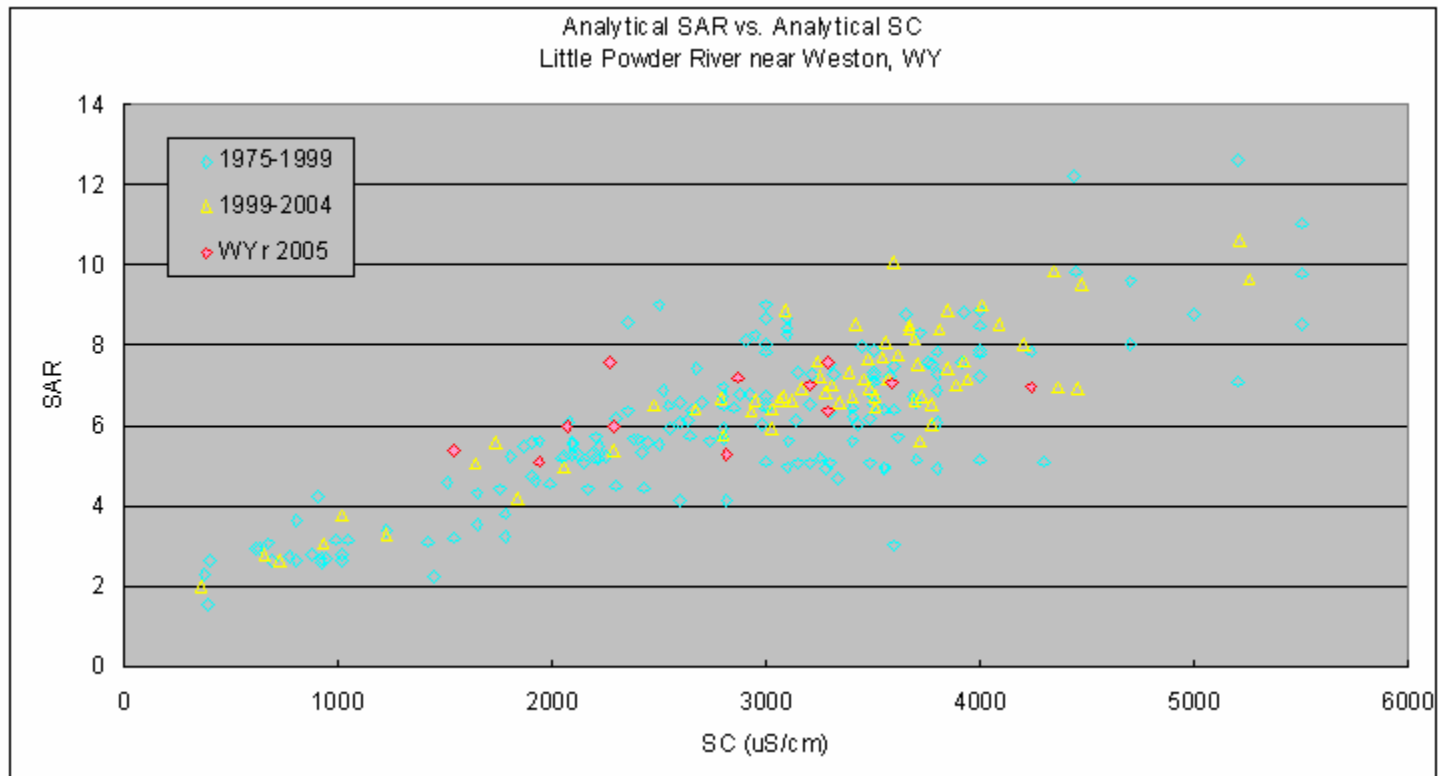


Figure 42 shows analytical SAR vs. analytical SC data for water year 2005 for the Little Powder River near Weston. Historical SAR vs. SC data are also shown to place the data in context.

Figure 43: Little Powder River near Broadus, MT

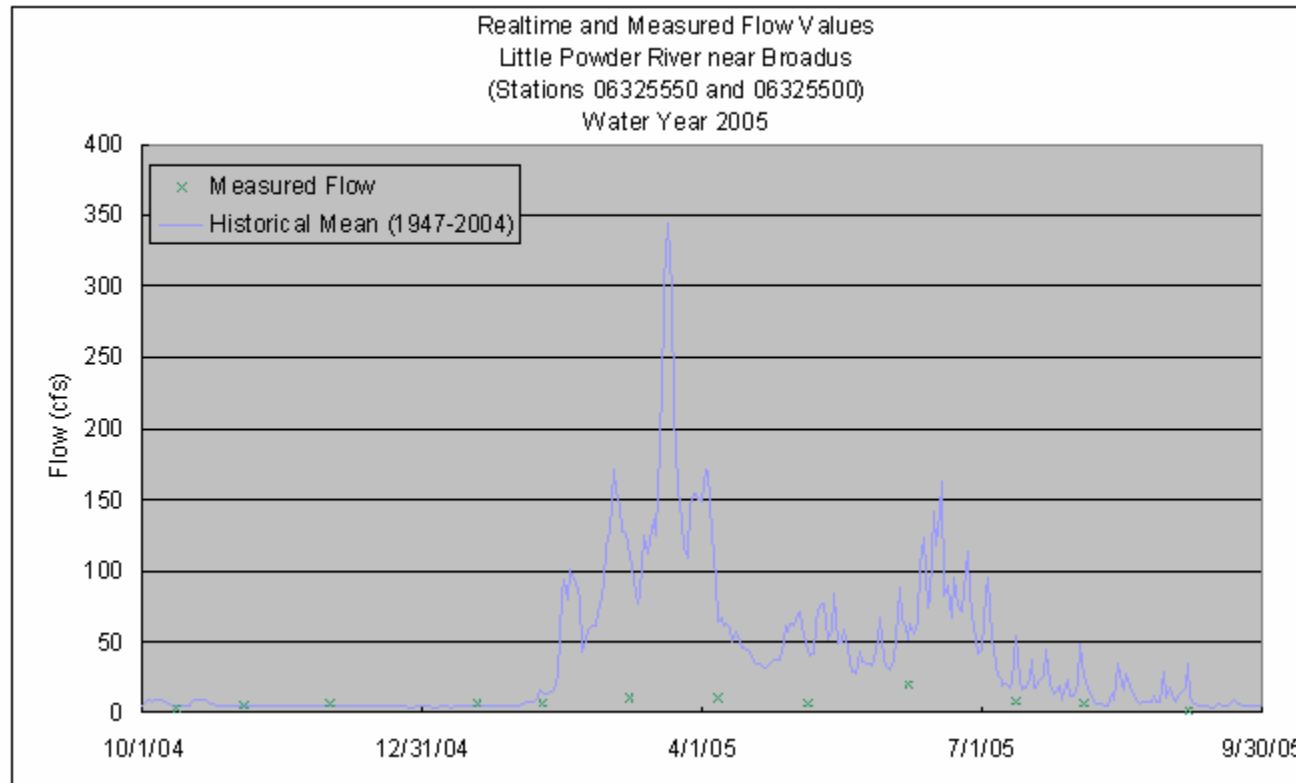


Figure 43 shows field measurements of flow in a time series plot for water year 2005 for the Little Powder River near Broadus. Recorded flow values ranged from 1.4 to 20 cfs. The historical average mean daily flow values are also shown to place the data in context.

Figure 44: Little Powder River near Broadus, MT

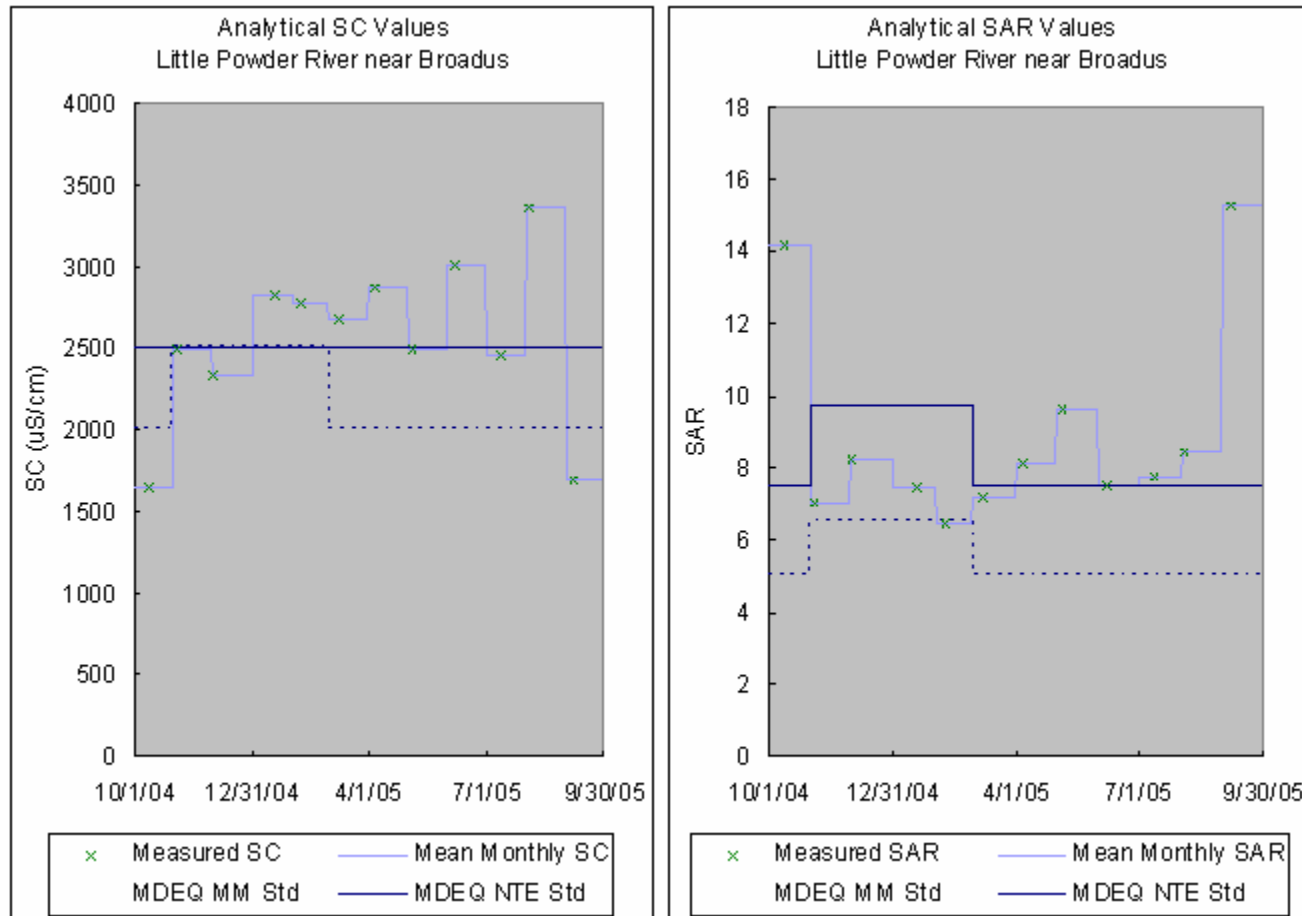


Figure 44 shows analytical SC values (A) and analytical SAR values (B) values in time series plots for water year 2005 for the Little Powder River near Broadus. Mean Monthly SC and SAR values are also shown. SC values ranged from 1650 to 3360 uS/cm. SAR values ranged from 6.5 to 15. MDEQ standards are also displayed for comparison.

Figure 45: Little Powder River near Broadus, MT

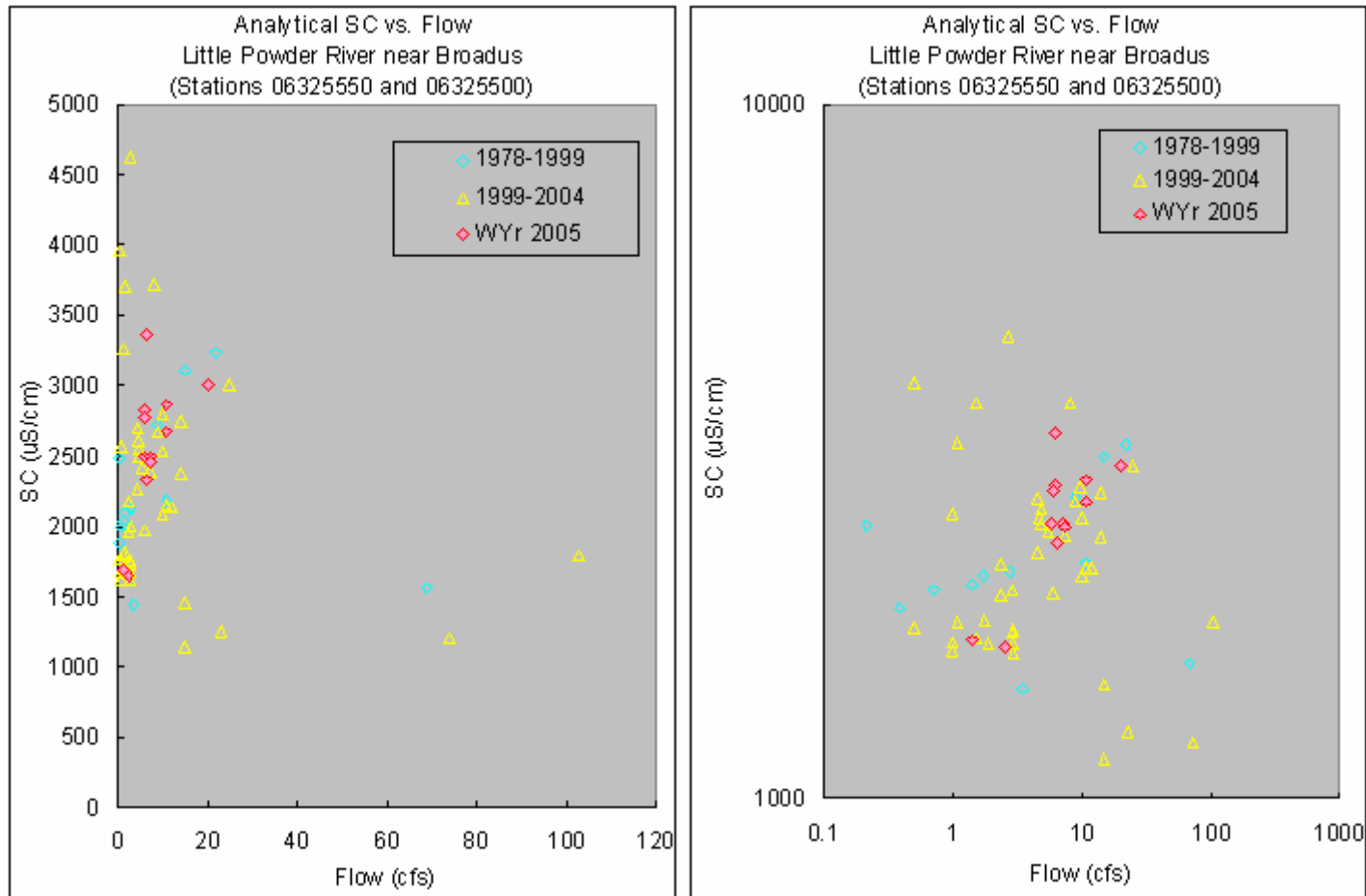


Figure 45 shows analytical SC vs. Flow data for water year 2005 for the Little Powder River near Broadus. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 46: Little Powder River near Broadus, MT

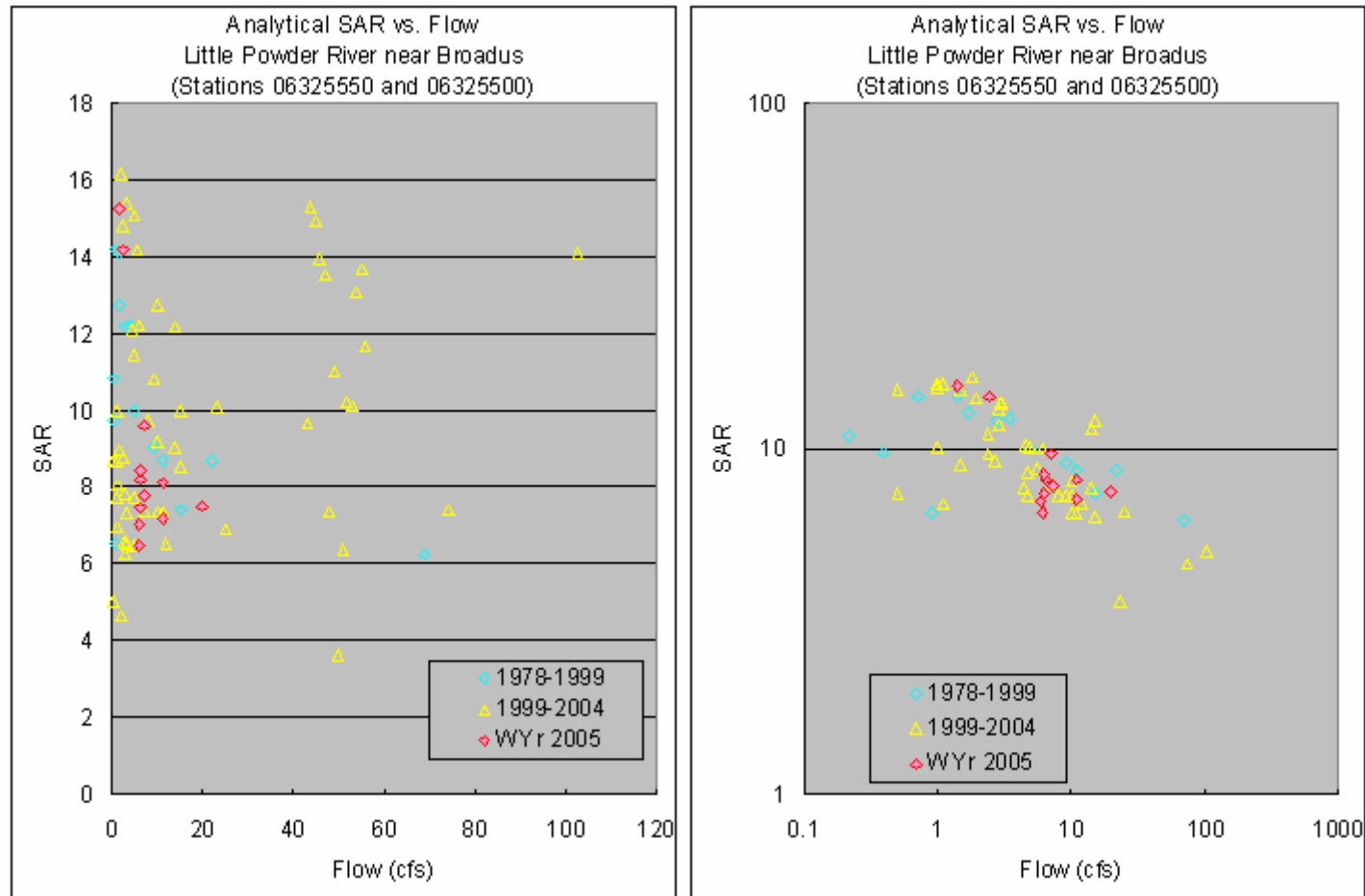


Figure 46 shows analytical SAR vs. Flow data for water year 2005 for the Little Powder River near Broadus. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 47: Little Powder River near Broadus, MT

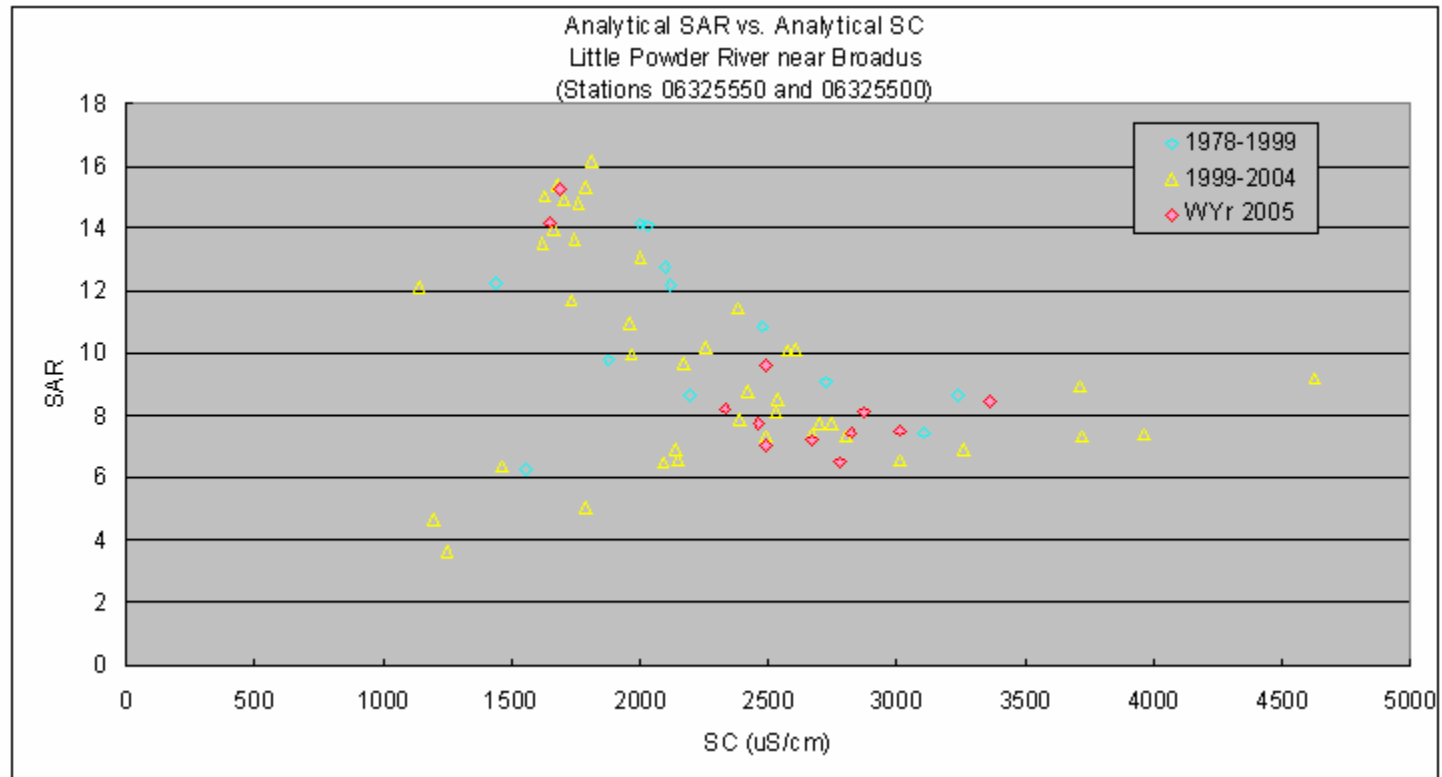


Figure 47 shows analytical SAR vs. analytical SC data for water year 2005 for the Little Powder River near Broadus. Historical SAR vs. SC data are also shown to place the data in context.